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THE STUDENT'S HANDBOOK

OF

STRATIGRAPHICAL GEOLOGY

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OF

STRATIGRAPHICAL GEOLOGY

BY

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ILLUSTRATED WITH MAPS, DIAGRAMS, AND FIGURES OF FOSSILS

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CHAPTER I

INTRODUCTION

Scope of the Subject.—In most manuals of Geology this branch of the subject is called Stratigraphical Geology because it chiefly consists in the description of the great stratified series of rocks which make up the mass of the earth's crust. It is sometimes called Historical Geology, because it should comprise not only a description of the various rocks which were formed during each period of the world's history, but also some account of the forms of life which are entombed in these rocks, with a sketch of the physical geography of the earth during each period, and a notice of the changes in the relative position of land and sea which took place from time to time; all this should be made as complete as the imperfection of the geological documents will allow.

Neither designation is quite satisfactory, but either of them may be used so long as it is understood to mean a geological history —a collation of the knowledge acquired in all the other departments of the Science, and its application to elucidate the history of the earth, or of a portion of the earth, from the earliest time of which any records exist down to the time of human history.

At present there are only a few limited areas of the earth's surface about which we have anything like a full stratigraphical knowledge, and much remains to be learnt even in the areas about which we know most. Geological History, therefore, is yet in its infancy; but enough is now known of the stratigraphical geology of Europe to make it possible to give an outline of its geological history, and American geologists are rapidly making it possible to do the same for North America. In this volume, however, we shall not travel beyond the limits of the British Islands, except where our own records are deficient, or where some knowledge of continental geology is necessary to the proper understanding of the changes that took place in Britain.

The Succession of Stratified Rocks.—The general principles on which historical geology is founded are easily understood, and the manner in which the order and succession of rock-groups is established will now be briefly explained. The mere succession of strata in any district or country, however, is one thing, and the grouping of such strata into larger systems, representing definite geological periods, is another thing, and one which requires consideration from several points of view. A subsequent chapter, therefore, will be devoted to a discussion of the principles upon which divisional lines may be drawn in any established succession of rock-groups.

The two principal tests by which the relative age of different strata is determined are—(1), Superposition ; (2), Fossil contents.

The conclusions to be drawn from the superposition of strata are explained in most text-books of physical geology, and the law of vertical succession which forms the basis of the whole fabric of historical geology may be stated as follows :—"In any succession of beds each one represents the conditions which prevailed over a certain area for a certain length of time, the lowest is the oldest, the uppermost is the newest, and the relative age of the others is indicated by their relative position." If the strata are inclined, the right order is ascertained by making a geological survey of the district, and constructing a section at right angles to the general strike of the beds.

Again, by tracing any one set of strata horizontally along their strike from one part of a district to another, where perhaps there are other rocks of a different kind, we obtain a datum of reference by which to determine whether the rocks in the second area are newer or older than those in the first.

So long as there is physical and geological continuity between the different portions of a district, *i.e.* so long as some one member of a conformable series of strata can be followed continuously, such a survey generally affords sufficient data for ascertaining the relative position of the rocks which occur in the district, and for constructing a table of their vertical succession. But when either geographical or geological continuity is interrupted—that is, when a district or country is separated from others of like structure either by the sea or by tracts of totally different rocks—then we must begin all over again, and construct an independent table of strata for the new district. For example, Wales is a district to all parts of which one system of classification and nomenclature can be applied. Similar groups of rocks occur in Ireland on the one hand, and in Cumberland on the other ; but Wales is physically separated from Ireland by the Irish Sea, and geologically separated from Cumberland by the

Triassic plains of Cheshire and Lancashire ; hence the same system of nomenclature could not be used in the other districts, the vertical succession had to be determined independently, and local names given to the different subdivisions in each district before they could be in any way compared with one another.

But, it may be asked, when two such districts have been independently investigated, how are we to correlate the two tables of strata, and ascertain which rocks or rock-groups were approximately contemporaneous? It is here that a knowledge of fossils (Palæontology) comes to our aid, and enables us to identify rocks by their fossil contents, so that strata in different districts and of different lithological characters may be included in the same natural group or system, because they contain the same or closely similar species of fossils. This was the principle discovered and applied at the beginning of this century by Dr. William Smith, who is often called the Father of British Geology, and who was certainly the founder of that branch of the science which is the subject of the present volume.

The book in which Smith recorded his discovery of the stratigraphical use of fossils was entitled *Strata identified by Organised Fossils*, and was published in 1816. He had previously made out the succession of the strata which occur near Bath, and had observed that each well-marked group of beds contained a special assemblage of fossils. As his acquaintance with English rocks became larger he noticed that there was a similar succession elsewhere, and thus (in the words of his nephew and biographer [1]) "he inferred that each of the separate periods occupied in the formation of the strata was accompanied by a peculiar series of the forms of organic life, that these forms characterised those periods, and that the different strata could be identified in different localities and otherwise doubtful cases by peculiar embedded organic remains."

The experience of subsequent observers confirmed and established this inference, which has become a guiding principle in stratigraphical geology. Further research, moreover, has brought out the more definite conclusion that there has been a continuous succession of life-forms, that species and genera and families, and even whole orders of beings, have come into existence, have flourished, and have then gradually died out, never to recur. It is this *non-recurrence* of species which gives a special value to fossils as a test of age and as a means of correlation. The same kind of rock has been formed again and again during the history of the world, but when once a species has died out it has never appeared again.

It must not be supposed, however, that the stratigraphical

[1] *Memoirs of William Smith*, by John Phillips, F.R.S., 1844.

succession of rocks presents us with a complete record of the history of the earth, or that it will ever supply us with examples of all the species which have lived upon the earth's surface. On the contrary, the records preserved to us are very incomplete, and many pages are wanting in every chapter of the great volume, so that Stratigraphical Geology cannot be defined as a *history of the earth;* it would be more correctly described as *scenes from the history of the earth.*

The causes which have produced this "imperfection of the record" will be indicated in the next chapter. The reader will then be prepared to enter more fully into the principles on which the long succession of formations has been divided into systems, and the grounds on which these systems have been subdivided into rock-groups of fairly equivalent value. Finally, a few words on the distribution of species at the present day will explain some limitations in the application of palæontological evidence, and prepare him for the distinction between *synchronism* and *homotaxis* in correlating the rock-groups of different countries.

From the above remarks it will be obvious that some previous knowledge of physical geology and of zoology is a necessary preparation to the study of Stratigraphical Geology. The reader may gain the first from any elementary manual of geology or from the author's *Handbook of Physical Geology* (G. Bell and Sons); and Woods's *Elementary Palæontology* (Cambridge Univ. Press) will furnish him with a good introduction to the palæontology of the Invertebrata.

For the purpose of convenient reference an outline of the general classification of the animal kingdom is here appended, the arrangement of the Invertebrate classes being substantially that to be found in Zittel's *Palæontology* and in Woods's *Elementary Palæontology*, except that in the classification of the Echinoderma I have followed Messrs. Bather and Gregory. The arrangement of the Vertebrata is based on that given in A. S. Woodward's *Outlines of Vertebrate Palæontology.*

Sub-kingdoms.	Classes.	Orders found fossil.
PROTOZOA	Rhizopoda	Foraminifera.
		Radiolaria.
	Infusoria	(No fossil forms).
	Sporozoa	(No fossil forms).
CŒLENTERA	Porifera	Calcarea.
		Hexactinellidæ.
		Demospongia.
	Anthozoa or Actinozoa	Zoantharia.
		Alcyonaria.
	Hydrozoa	Hydrocorallinæ.
		Stromatoporoidea.
		Graptolitoidea.
ECHINODERMA	Blastoidea	Protoblastoidea.
		Eublastoidea.
	Cystidea	Amphoridea.
		Rhombifera.
	Edrioasteroidea.	
	Crinoidea	Monocyclica.
		Dicyclica.
	Stelleroidea	Asteroidea.
		Ophiuroidea.
	Echinoidea	Regularia.
		Irregularia.
	Holothuroidea	Occasionally fossil.
"WORMS"	Platyhelmia	No fossil forms.
	Nemerti	No fossil forms.
	Rotifera	No fossil forms.
	Annelida	Chætopoda.
MOLLUSCOIDEA	Bryozoa	Gymnolæmata.
	Brachiopoda	Inarticulata.
		Articulata.
MOLLUSCA	Pelecypoda or Lamellibranchia	Prionodesmacea.
		Anomalodesmacea.
		Teleodesmacea.
	Scaphopoda	(Dentalium, etc.)
	Amphineura	Polyplacophora.
	Gastropoda	Streptoneura.
		Euthyneura.
	Cephalopoda	Tetrabranchiata.
		Dibranchiata.
ARTHROPODA	Crustacea	Trilobita.
		Entomostraca.
		Malacostraca.
		Cirripedia.
	Acerata	Merostomata.
		Arachnida.
	Myriapoda	Rare as fossils.
	Insecta	Aptera.
		Orthoptera.
		Neuroptera.
		Hemiptera.
		Coleoptera.
		Diptera.
		Lepidoptera.
		Hymenoptera.

Sub-kingdoms.	Classes.	Orders found fossil.
CHORDATA	Tunicata, etc	Few fossil forms.
VERTEBRATA	Agnatha	Marsipobranchii.
		Ostracodermi.
	Pisces	Chimæroidei.
		Elasmobranchii.
		Dipnoi.
		Teleostomi.
	Amphibia	Urodela.
		Anura.
		Labyrinthodonta.
	Reptilia	Chelonia.
		Lacertilia.
		Ophidia.
		Crocodilia.
		Plesiosauria.
		Ichthyosauria.
		Anomodontia.
		Rhynchocephalia.
		Dinosauria
		Pterosauria.
	Aves	Archæornithes.
		Odontornithes.
		Ratitæ.
		Carinatæ.
	Mammalia	Prototheria.
		Marsupialia.
		Edentata.
		Sirenia.
		Cetacea.
		Ungulata.
		Rodentia.
		Carnivora.
		Insectivora.
		Cheiroptera.
		Primates.

CHAPTER II

ORIGIN AND SUCCESSION OF SPECIES

Origin of Species.—At the outset of this inquiry we are met by the question, What is a species? Before the publication of Darwin's book on the *Origin of Species* most people regarded a species as the result of a special creation of a definite kind of plant or animal, yet all who studied either plants or animals were obliged to admit that some species displayed many varieties, and also that it was difficult to say what amount of difference should constitute a species.

Lamarck in 1801 was the first to propound the doctrine that all existing species are descended from other species, but few naturalists gave credence to his views, and it was not till 1859, when Darwin published his book, that the world became familiar with such a doctrine.

On the primary point of the appreciation of differences Darwin remarks (*Origin of Species*, sixth edition, p. 41), "Certainly no clear line of demarcation has yet been drawn between species and sub-species—that is, the forms which in the opinion of some naturalists come very near to, but do not quite arrive at, the rank of species; or again between sub-species and well-marked varieties, or between lesser varieties and individual differences; and a series [of specimens] impresses the mind with the idea of an actual passage." Further on he says, "From these remarks it will be seen that I look at the term species as one arbitrarily given, for the sake of convenience, to a set of individuals closely resembling each other, and that it does essentially differ from the term variety, which is given to less distinct and more fluctuating forms."

Darwin and Wallace developed their views about the same time, and both accounted for the existence of so many varieties, species, and genera of organisms by indicating the various causes and conditions which influence all kinds of organisms and tend to

modify their habits, forms, and members. They have shown how the constant struggle for existence and the frequent changes of environment may have developed or have increased a tendency to variation, and how this variation results in the formation of varieties and species. Natural selection (or the selective action of natural processes) results also in the extinction of many forms and in the survival of a few—namely, of those few which are the most capable of accommodating themselves to the more rigorous and changed conditions of existence. This is called the "survival of the fittest." It is by the infinite repetition of these processes that species which are now widely different may have been evolved from a common ancestor.

Another consequence of natural selection is the preservation of those varieties and species which chance to possess peculiarities that are useful to them in the struggle for existence. Thus as Darwin says (*op. cit.* p. 103), "it leads to the improvement of each creature in relation to its organic and inorganic conditions of life, and consequently in most cases to what must be regarded as an advance in organisation." In other words, it leads to the evolution of higher and higher forms of life.

Now if the descendants of varieties may become different species, and if the descendants of different species may in course of time become so differentiated that most naturalists would rank them as different genera, and if this process has been going on during the whole of geological time, since the world first became fit to support life; then we might expect that the successive assemblages of fossils preserved for us in the rocks of the earth's crust would furnish us with a long succession of links between one species and another, and would connect the generic forms of the present with those which have long been extinct. Unfortunately, however, though many such links have been found, and though more come to light every year, so that the genealogy of many genera can be satisfactorily made out, yet there are reasons why we can never hope to find all the links in the chain.

Imperfection of the Geological Record.—That the truth of Darwin's theory of the origin of species cannot at once be proved, and the complete genealogy of modern genera be constructed from the records of the past, is due to the imperfection of that very geological record which would otherwise contain the obvious proof or refutation of the hypothesis. This imperfection results from two causes, (1) the conditions which limit the entombment and preservation of organic remains, (2) the frequent erosion and destruction of the deposits in which they have been buried.

1. *Conditions of Entombment.*—If we consider the manner in

which deposits are now taking place, we shall perceive that the preservation of many kinds of organic remains in these deposits is likely to be an exceptional and accidental occurrence. Deposition of sediment is not an uninterrupted process likely to ensure the conservation of specimens of the greater number of plants and animals living at any one time, but is, on the contrary, so discontinuous that only a small proportion of any fauna or flora would be entombed in such a way as to be permanently preserved, either in terrestrial or marine deposits.

On land, generations of animals may die and moulder away, shells, bones, and all, without any remains being transported to places where deposits are accumulating. Mr. F. C. Selous remarks that in South Africa "no organic matter lasts very long when exposed to the weather, and even the skull and leg bones of an elephant would, I think, crumble to dust and absolutely disappear in less than fifteen years from the date of the animal's death."[1] In some countries where the climate is very dry they last more than fifteen years, but still ultimately decay and crumble into dust.

Of the larger land animals a few are occasionally buried in bogs or drowned in lakes and rivers, and still fewer are carried down by rivers to the sea. The animals which live in fresh water and the leaves of plants stand a better chance of preservation in those parts of the country where lacustrine and fluviatile deposits are being formed; but these purely freshwater beds occupy but small areas, and are particularly liable to subsequent destruction, so that as a rule our knowledge of the terrestrial and fluviatile fauna of any period is derived from the specimens which were carried down the streams during floods, and were buried in the estuarine deposits at the mouths of large rivers.

The creatures which inhabit the sea have a much better chance of being preserved as fossils, since deposits of one kind or another are constantly being formed over large areas of the sea-bottom, especially where subsidence is in progress. Yet even among marine forms of life there are many which would only rarely be entombed; those animals, for instance, which live on rocky shores and in clear water would not be preserved except where deposits of limestone were in process of formation. The majority of the creatures embedded would be those which lived on sandy and muddy bottoms, together with some of the free-swimming forms which moved through the water above.

Lastly, of the creatures so embedded only a small proportion would ultimately remain; those, namely, which possessed hard

[1] *Sport and Travel*, by F. C. Selous, 1900, p. 156.

structures capable of fossilisation after the softer parts had decayed and disappeared. The following table shows at a glance which kinds of animals, out of all those which live in the sea, would be likely to leave memorials behind them and which would perish without leaving any trace of their existence.

Sub-kingdoms.	Groups with Hard Structures.		Perishable Groups.
Protozoa.	Foraminifera.		Flagellata.
	Radiolaria.		Infusoria.
Porifera.	Silicispongiæ.		Myxospongiæ.
	Calcispongiæ.		Ceratospongiæ.
Cœlenterata.	Sertularida.		Hydroida (except Sertularida).
	Hydrocorallina.		
	Graptolitoida.		Siphonophora.
	Stromatoporoidea.		Discophora.
	Madreporaria.		Actiniaria.
	Some Alcyonaria.		Alcyonaria (some).
			Ctenophora.
Echinoderma.	All classes.		None.
Vermes.	Tubicola and the horny jaws of Nereids.		Hirudinea.
			Oligochæta.
Anthropoda.	All classes.		
Molluscoida.	Bryozoa.		
	Brachiopoda.		
Mollusca.	Lamellibranchia.		
	Scaphopoda.		
	Gastropoda	except	Nudibranchiata.
	Cephalopoda	except	some Cuttle-fish.
Vertebrata.	Teeth, bones, and scales of all kinds.		Tunicata.

But although all the classes of creatures entered in the second column possess hard parts which are capable of preservation, it does not follow that these are always preserved. Their conversion into fossils depends partly on the solidity and character of the substance of which the hard parts are composed, and partly on the rapidity with which the remains are covered up and embedded in sediment. Lastly, their final preservation as fossils depends upon the conditions to which the embedding rock is subsequently exposed, upon its conservation or destruction.

The remains of those creatures which live in deep water or over deep water, such as many Foraminifera, Radiolaria, siliceous sponges, and pteropods, have such delicate tests and spicules that they often fall to pieces and become mere *debris* before they can be embedded in sediment; for in deep water the accumulation of sediment is usually a very slow process. The thin shells of the Radiolaria and the Pteropoda are especially liable to rapid disintegration, and consequently they are rare as fossils, although they are known to have existed from very early times.

Subsequent Removal of Organic Remains.—The proportion of those remains which would otherwise be preserved is further diminished by the subsequent destruction of some of them by the action of percolating water. All water which percolates downward from terrestrial surfaces contains carbonic acid, and such carbonated water attacks and dissolves carbonate of lime, and also that form of silica which enters into organic structures. Hence all such embedded remains are liable to solution and removal under certain circumstances.

So long as the deposit containing embedded organisms remains below the sea in which it was formed, it is probable that the changes which take place are slight and gradual. It is when the fossiliferous deposit is raised above the level of the sea and is added to the dry land that changes are apt to take place. Even then, if the rock has formed part of a thick series deposited during a long period of subsidence, and has remained buried beneath others for some time before the whole mass is raised to form land, most of the fossils in it are likely to be preserved, for the rock becomes consolidated and remains saturated with saline water, which probably contains as much carbonate of lime as it is capable of holding in solution under such conditions. Many fossils exhibit changes of structure which have very probably been effected during upheaval and while the rock was in a water-soaked condition; thus the substance of shells is frequently converted into crystalline calcite, and in other cases the calcareous shell is replaced by chalcedonic silica.

Those parts of a formation, however, which come to form the surface portions of newly-raised land, *i.e.* those parts which are raised above the lowest summer level of saturation, are subjected to the action of percolating water, with the result that many shells are dissolved, leaving only the hollows in which they lay. These hollow spaces may remain empty or they may be filled subsequently with infiltrated mineral matter, or if disturbances take place before the final consolidation of the rock, the internal cast may be squeezed on to the external impression of the shell and receive an impress of its ornamentation. In any of these cases some record of the original organism remains, but if the rock material is a loose sand or other very soft kind of sediment all trace of the organism may be destroyed.

With regard to the durability of the original shell much depends on its original mineral composition. In some shells and tests the carbonate of lime consists of the variety known as *calcite*, while in others it has the structure of *arragonite*, and it is a well-ascertained fact that arragonite is much less stable than calcite.

It was pointed out by Mr. Sorby[1] that shells composed of arragonite disappeared much faster than the calcite shells when both were exposed to carbonated waters, and he pointed out that the creatures which possess hard calcareous structures can be separated into two sets according to the nature of the calcareous substance. These two sets may be tabulated as follows :—

Calcitic Structures.	Arragonite Structures.
Foraminifera.	Calcareous sponges.
Echinodermata.	Actinozoa (corals, etc.)
Annelida.	Lamellibranchia (except Oysters,
Most Bryozoa.	Pectens, and the outer layer of
Brachiopoda.	Spondylus, Pinna, and Mytilus.
Oysters and Pectens.	Gastropoda (with a few exceptions).
Crustacea.	Cephalopoda.

Professor P. F. Kendall has also made observations and experiments which confirm those of Mr. Sorby.[2] He has pointed out that in the Coralline Crag of Aldeburgh some fossils remain perfect, while of others there are only casts, and that the casts are without exception of arragonite shells, while the former are calcitic structures, such as Bryozoa, Echinoderms, Serpulæ, Brachiopoda, and the bivalve Molluscan genera, *Anomia*, *Ostrea*, *Pecten*, *Lima*, and *Pinna;* with the latter, however, occurred the Gastropod shell *Scalaria*, which he thought must be calcitic, an inference which subsequent experiment proved to be correct.

Destruction of Fossiliferous Deposits.—There is another set of agencies which contribute to render the geological record a very imperfect one. When any mass of marine deposit is raised into land, there is not only an absence of deposition, but there commences an actual destruction of the records previously accumulated. In the first place, as the rising deposit passes through the plane of the sea-level, it is exposed to the erosion of the waves, and if the latest deposits are not very thick, and the process of elevation is not very rapid, the probability is that only small portions will escape destruction. These portions will remain for a time as plains, marsh lands, and raised beaches ; but as elevation continues, they will be brought gradually under the influence of atmospheric agencies, and exposed to continual wear and tear so long as they remain above the sea.

It follows, therefore, that only deposits of considerable thickness will survive the attacks of destructive agencies, and remain to form a permanent part of the earth's crust, but thick deposits cannot be accumulated in shallow seas, *which are the most favourable to life*,

[1] *Quart. Journ. Geol. Soc.* vol. xxxv. (1879), Pres. Address.
[2] *Geol. Mag.* 2nd Dec. vol. x. p. 497.

so long as the sea-bed remains stationary or is being elevated. Thick formations can only be accumulated in areas where constant subsidence has been in progress, or where the shore originally shelved rapidly into deep water, as off the coast of the Riviera. In the latter case the sediment will be rapidly accumulated, and will not contain so many or such varied forms of life; but under the former conditions, if the supply of sediment was sufficient to keep the sea shallow and to embed the organic remains, a formation rich in fossils, and thick enough, when upraised, to resist erosion, would be formed. We must, therefore, conclude with Darwin, "that nearly all our ancient formations, which are throughout the greater part of their thickness *rich in fossils*, have thus been formed during subsidence." [1]

This conclusion that most of our great fossil-bearing formations have been deposited during subsidence has a very important bearing on the question before us, viz. whether the rocks are likely to contain the remains of an uninterrupted succession of species, or whether the record is more or less incomplete; for, as Darwin remarks:—

"During periods of elevation the area of the land and of the adjoining shoal parts of the sea will be increased, and new stations will often be formed—all circumstances favourable, as previously explained, for the formation of new varieties and species; but during such periods there will generally be a blank in the geological record. On the other hand, during subsidence the inhabited area and number of inhabitants will decrease (excepting on the shores of a continent when first broken up into an archipelago), and consequently during subsidence, though there will be much extinction, few new varieties or species will be formed; and it is during these very periods of subsidence that the deposits which are richest in fossils have been accumulated." [2]

Succession of Life-forms.—From the considerations above mentioned it will be seen that we cannot expect to find all the transitional forms which, if the theory of evolution be correct, must have connected one species with another, and have linked together all the past and present species of any one genus into one long chain of life. All that we can hope to find are certain cases where so large a number of closely-allied species and varieties have been preserved as to furnish us with strong evidence of their having been links in such a chain.

There are, moreover, two well-established generalisations from palæontological facts which lead to a very significant inference; these considerations are (1) that the assemblage of fossils found in

[1] *Origin of Species*, sixth edition, p. 273.
[2] *Op. cit.* p. 275.

any formation has a general character intermediate between the assemblages above and below; and (2) that the fossils from two consecutive formations are far more closely related to each other than the fossils from two more remote formations. Commenting on these Darwin observes:[1] "On the theory of descent, the full meaning of the fossil remains from closely consecutive formations being closely related, though ranked as distinct species, is obvious. As the accumulation of each formation has often been interrupted, we ought not to expect to find in any one, or in any two, formations all the intermediate varieties between the species which occurred at the commencement and the close of those formations; but we ought to find, after intervals very long as measured by years, but only moderately long as measured geologically, closely allied forms, or, as they have been called by some authors, representative species; and these assuredly we do find.. We find, in short, such evidence of the slow and scarcely sensible mutations of specific forms as we have the right to expect."

In spite, therefore, of the imperfection of the record, the known succession of life-forms does give very great support to the theory of evolution. Every succeeding fossil assemblage contains not only a larger number and greater variety of forms, but also some which are distinctly more specialised and more advanced in organisation. It is an acknowledged fact that many of the more ancient forms of life were what are termed "comprehensive types," *i.e.* types which combine the structural characters of two or more different orders or classes of creatures, which are now completely differentiated from each other. In many cases also ancient animals resemble the embryos of the more recent animals belonging to the same classes.

Beyond all this there can be traced a distinct and decided progress in the types of life as we ascend the geological scale. It is true that in the earliest fauna yet known we start with a number of more or less specialised invertebrate types, but the more highly organised orders of Gastropods, Cephalopods, Crustacea, and Echinoderms do not appear till later periods; Fish are not known earlier than Silurian times; Amphibia commence in the Carboniferous; Reptiles in the Permian and Trias; Birds in the Jurassic; Mammals of low organisation in the Trias; higher Mammals, including Lemurs, appear in the Eocene, but true monkeys are not yet known from beds of greater age than the Miocene.

[1] *Op. cit.* sixth edition, p. 307.

CHAPTER III

THE CLASSIFICATION OF ROCK-GROUPS

As soon as it was recognised that the rocks which compose the earth's crust were not a mere congeries of rock-masses without order or sequence, but that when properly interpreted they arranged themselves in an orderly succession of formations, then it was seen to be necessary that names should be given to all parts of this wonderful succession of stratified deposits.

The history which can be read from the "records of the rocks" is a very long one, although, as has already been stated, it is by no means a complete history. Every natural region of the earth's surface has its own geological history, but the same great periods of time can be recognised in all. Geological history, like human history, has its early or pristine times, its mediæval times, and its later or more modern times; it may perhaps be said to consist of several volumes, and of course each of these volumes consists of several chapters dealing with so many successive periods.

Stratigraphical nomenclature is not very satisfactory, for it has been gradually developed in a synthetic manner, and is not the consistent and harmonious arrangement which it might have been had the older geologists possessed our present knowledge of the rocks. In early days the greater rock-groups were generally called *formations;* thus we read of the Old Red Sandstone formation, the New Red Sandstone formation, the Carboniferous formation, and the Chalk formation. Afterwards, as a knowledge of their fossil contents increased, the relative time-values of these formations were better understood, and some of them were united with others to form systems; but the number of such systems was not fixed, nor did any definite idea exist as to what entitled a series of rocks to rank as a system. There is still some difference of opinion on this point, but doubtless agreement will ultimately be attained.

It was also early perceived that the older formations differed very greatly from the later deposits both in mineral characters and

in fossil contents. It was noticed that the oldest rocks were generally crystalline schists, that the next oldest were more or less altered and indurated, while the later were often soft and clearly stratified, and the most recent were usually loose and unconsolidated. Hence Werner in Germany used names which may be translated as equivalent to *primitive*, *transition*, *stratified*, and *alluvial* rocks, and the French introduced the more convenient terms *Primary*, *Secondary*, and *Tertiary* divisions.

It was supposed that the rocks belonging to these eras of time differed essentially in their original nature and mode of formation. Subsequent investigation proved this idea to be an error, and Professor Phillips consequently proposed another set of names for the eras based on palæontological facts, namely, *Palæozoic*, *Mesozoic*, and *Cænozoic*, signifying respectively times of ancient, middle, and recent life. The two former of these have been very generally adopted, but Tertiary is still preferred to Cænozoic, and there is no reason now why its correlatives, Primary and Secondary, should not be employed as time-words, instead of the more cumbrous Palæozoic and Mesozoic.

Professor E. Forbes thought that the faunas of the Secondary and Tertiary had so great an affinity that the whole succession was more naturally divisible into two eras, which he termed Palæozoic and Neozoic. No doubt this is strictly correct, but the triple division has been found very convenient in Europe, and is more generally adopted.

Since these terms were proposed, however, a series of stratified rocks have been discovered below those which were called Primary or Palæozoic, and for these several names have been proposed. Of these Pre-Cambrian is the best, for *Archæan* has been used in a restricted sense, and the others, *Azoic* and *Eozoic*, are founded on the respective assumptions (1) that they contain no organic remains, (2) that they contain the relics of the first dawn of life in the world. Such small traces of life as have been discovered in these rocks do not suggest anything very different from that of Palæozoic time, but they may for the present be termed Pre-Cambrian or Eozoic.[1]

In the following table of systems the oldest is placed at the bottom and the newest at the top to indicate their natural superposition and order in the chronological scale.

[1] Professor Lapworth divides the Palæozoic series into an older and a newer division, which he terms *Protozoic* and *Deutozoic* respectively, but if these names are used, the Secondary era should become the *Tritozoic* and the Tertiary the *Tetartozoic*. The term Quaternary I regard as superfluous and misleading, and it will not be used in this book.

Systems.	Eras.	
Pleistocene, Pliocene, and Miocene	Tertiary or Cænozoic	Neozoic.
Oligocene and Eocene		
Cretaceous	Secondary or Mesozoic	
Jurassic		
Triassic		
Permian	Primary or Palæozoic.	
Carboniferous		
Devonian and Old Red Sandstone		
Silurian		
Ordovician		
Cambrian		
Longmyndian	Pre-Cambrian or Eozoic.	
Uriconian		
Torridonian		
Lewisian		

Nomenclature.—With regard to the names of the systems in the above table some explanation is required. Such names as Old Red Sandstone, Carboniferous, and Cretaceous are used in a far wider sense than their mere lithological signification. These names were originally given to certain British formations, in which the most conspicuous elements were respectively red sandstone, beds of coal, and chalk; but they have since acquired a chronological meaning, and are used as systematic names for the periods of time during which the rocks were formed. Some of them have also been adopted in other countries for rock-groups, which occupy the same relative place in the geological succession.

The Cretaceous system then includes, not only the Chalk, but also the beds of sand and clay which underlie it, and contain a similar assemblage of genera and species. Moreover, the Cretaceous system includes not only the Chalk and its associated beds in Europe, but all the rocks which were formed during the same period of the earth's history. Elsewhere, therefore, as in North America, the system may consist of sandstones, shales, and coal-seams without a bed of real chalk in it.

So the Carboniferous system means that system of strata of which the *British* Coal-measures form an integral part, but which includes several other rock-groups, all united by a community of fossils. It is these fossils, and not the occurrence of coal-seams, which are the criterion of the so-called Carboniferous period, for, as above mentioned, in America there are coals of Cretaceous age. In the same way, when we speak of the Carboniferous Limestone series, we do not mean a group which everywhere consists of limestone, but one to which the great Carboniferous Limestone belongs; when traced northward through England, this limestone is found

to split up into separate beds, which finally become subordinate to thick masses of sandstone and shale.

The Old Red Sandstone is a particularly awkward and unsatisfactory name for an important group of rocks. It is supposed to be the freshwater or estuarine equivalent of the Devonian, and was originally applied to a series in which red sandstones predominated, and was called *old* because it lay beneath the Carboniferous rocks, above which came another group of similar red sandstones. The latter were formerly termed New Red Sandstone, but this name has been superseded by a less cumbrous nomenclature, and it is to be hoped that "Old Red Sandstone" also will soon be replaced by a better name. As Jukes observed forty years ago,[1] "it is avowedly a provisional designation, just exactly as the names of all the great groups of stratified rocks are provisional. They are temporary names adopted for present purposes, and have grown into use, and will continue to be used until they are superseded by more appropriate terms, which increasing knowledge only can show to be more appropriate."

In many respects those names which have a geographical or historical origin are the most satisfactory—names taken from those of towns, rivers, mountain ranges, provinces, or the ancient races which inhabited such provinces; as Jurassic (from the Jura range), Devonian (from the county of Devon), Cambrian (from the Roman name of North Wales), Silurian (from the tribe of the Silures). These will probably remain as permanent names for systems to which they are applied.

Definition and Delimitation of Systems.—The number of systems into which the geological series should be divided, and the horizons at which the planes of separation are placed, are points requiring some consideration, because they involve certain principles of classification. The divisional lines are generally drawn where natural breaks occur, either in the sequence of the strata themselves, or in the succession of fossil species which they contain. Such breaks are therefore of two kinds, (1) Stratigraphical, (2) Palæontological.

1. *Stratigraphical Breaks.*—The nature of stratigraphical breaks or unconformities is explained in all handbooks of physical geology, and in the present connection we have to deal only with their relative importance and value in classification. The most complete and satisfactory measure of any unconformity is the thickness of strata which were deposited in other areas during the time represented by the gap between the two unconformable formations.

It is not every unconformity which is of sufficient importance

[1] *Manual of Geology*, second edition, 1862, p. 429.

to form a plane of division between two systems. Thus there is unconformity in England between the two divisions of the Triassic system, and there is an unconformity between the Inferior Oolite and the Great Oolite series in Lincolnshire; but in each case the beds above and below the break are included in the same system on palæontological grounds.

A break which is represented elsewhere by several thousand feet of rock implies the lapse of a considerable period, and being always accompanied by a great change in the fossils, might be taken as a line of division between two systems. But if systems were to be rigidly limited by physical unconformities, and defined as a series of beds formed during a complete oscillation of downward and upward movement, the classification of the rocks in one area will break down when applied to those of other districts, because the gaps will occur at different horizons in different areas. Thus in Britain alone three different classifications at least would be required for the Primary rocks, as the following columns will show, a —— being taken to mean a break or unconformity.

Wales.	Scotland.	Ireland.
Carboniferous.	Carboniferous.	Carboniferous.
Upper O.R.S.	Upper O.R.S.	Upper O.R.S.
Middle O.R.S.	——	——
Lower O.R.S.	Lower O.R.S.	Lower O.R.S.
Silurian.	Silurian.	Silurian.
——		——
Ordovician.	Ordovician.	Ordovician.
	——	——
Cambrian.	Cambrian.	Cambrian.

Thus, if we adopted the arrangement warranted by the stratigraphical breaks which occur in Wales, we should have two separate systems, and two only, for there is a general conformity between the Cambrian and Ordovician, and from the Silurian to the Carboniferous. In Scotland, however, there are two breaks, one between the Cambrian and Ordovician, and another between the two members of the Old Red Sandstone, so that we should be obliged to recognise three separate systems. Again, if we pass into Ireland, we find no less than three breaks in different parts of the country, which would involve a further remodelling of the classification.

As in this case, so also in others, a classification founded on physical breaks may be conveniently used for a limited district, and until further knowledge is acquired; but the breaks in the succession are certain to be filled up elsewhere by transitional beds, and as these may be of systematic value, we must always be

prepared for the possible intercalation of another system between any two groups that are divided by a decided unconformity.[1]

In brief, it must be admitted that unconformities are *geological accidents*, and if our classification and nomenclature are to be applicable to any large section of the earth's crust, they must be based, not on stratigraphical, but on palæontological facts. The Ordovician, Devonian, and Jurassic are systems so established ; and, in process of time, as our knowledge becomes more and more complete, it is probable that the number of systems will be finally determined in the same manner. They will always be more or less arbitrary divisions, since it will be difficult to say what number of peculiar genera would entitle a series of beds to the rank of a system ; but a general agreement will doubtless be reached in time. Meanwhile the student will do well to regard our present classification as provisional, and to remember that, though divisional lines must be drawn somewhere, passage beds and transition groups are of frequent occurrence in nature.

2. *Palæontological Evidence.*—But although we must rely mainly on palæontological evidence in separating one system from another, it must not be supposed that every sudden change of fauna is to be taken as introducing a new system, or that such a change always indicates a period of non-deposition, and therefore a greater or less break in the succession ; unless this coincides with a physical break or unconformity, the mere fact of such a change does not necessarily prove any great lapse of time. The change may be caused in several ways, either by rapid depression, by a sudden immigration of new forms, or by elevation with or without continuous deposition.

It is conceivable, for instance, that rapid depression, causing a considerable increase in the depth of the water, and removing the area farther away from the coast line, would produce what has been termed a palæontological break in a comparatively short period of time, and without any discontinuity of deposit. The beds below a certain plane would embed the remains of a shore fauna, while those above it would contain a deep-water assemblage, which might be very different even if the deposits were of similar lithological character. Depression, by the submergence of barriers, may also cause much more extensive changes ; we have only to consider what would result from the submergence of certain existent isthmuses, such as those of Panama and Suez, to realise what must have repeatedly happened in the past. The balance of life in both provinces would be altogether disturbed and upset, resulting in the

[1] The student can read with advantage Professor Lapworth's article on the "Classification of the Lower Palæozoic Rocks" in the *Geological Magazine*, Dec. 2, vol. vi. p. 1 (1879).

extinction of some forms, the intermigration of others, and the development of some new varieties and species.

Moreover, an alteration in the physical geography of one area may indirectly, but very greatly, affect the climate and life of another distant area; thus, if the isthmus of Panama were now to be submerged, the Gulf Stream would probably be diverted from its present course, and the result would be an immediate refrigeration of the British climate and a consequent immigration of Boreal and Arctic species into the Celtic province. Conversely, if after some length of time the barrier were again upraised, and the warm current again deflected into its present course, the climate would be ameliorated, Boreal forms would disappear, and a more southern assemblage would once more occupy the area.

Elevation of the sea-bottom will produce similar direct changes to those caused by depression; a deep-sea area, where deposition has been very slow, may by elevation be brought nearer to a coast line, and beds containing a deep-sea fauna may be succeeded immediately by others more rapidly accumulated, and embedding a shallow water assemblage. The change of life in such a case would be great, but the lapse of time would not be correspondingly long. If, however, elevation is continued till the area is raised above the sea-level, and remains for a time as a land surface, then a plane of erosion will be formed, and the change of fauna will be accompanied by stratigraphical discontinuity. The break then may be very considerable, but it may or may not coincide with the epoch of change from one fauna to another in an adjacent area of subsidence.

Notwithstanding this, it is true that the continuity of deposition may outlast the duration of a certain fauna; and it may become necessary to draw a line between two faunas of systematic importance in the midst of a conformable series of strata; in such a case it will naturally be drawn where the greatest palæontological break occurs. In other words, a life-assemblage, characteristic of one period in the world's history, may continue to inhabit any area until such changes occur as to cause the introduction of an assemblage which has been gradually developed outside that area, and these changes may take place with or without interruption of deposition in that particular area.

From the preceding remarks it will be seen that it is impossible to define a system as a series of deposits formed during one complete downward and upward movement or oscillation of some one part of the earth's surface. Moreover, if we could so define a system, the systems of one region could not be coeval with those of other regions. Systems must therefore have a palæontological value, and a system may perhaps be defined as a consecutive

series of strata formed during the prevalence of certain generic forms of life throughout a large part of the earth's surface.

The student must be prepared to find that systems founded on the differences in successive faunas will not include anything like equal thicknesses of rock. If, as appears most probable, the differentiation of species and the development of higher forms has progressed in a constantly increasing ratio, it is clear that the time-value of systems based on such changes will become less and less as we approach modern times. It is certainly a fact that the same forms of life extend through a much greater thickness of rock in the earlier than in later geological times; and there is no reason for supposing that the production of rocks went on more rapidly (at any rate during later Palæozoic periods) than at the present time; limestones must always have been of slow and gradual growth, and yet the persistence of species through the Carboniferous Limestone series is truly remarkable, while the limestones of the Jurassic and Cretaceous periods, though of far less thickness, are divisible into numerous palæontological zones or belts, each having many species which do not appear in the next. The changes in the forms of life inhabiting any marine area being thus more rapid in later geological times, an equal amount of change would naturally be accomplished in less time, and consequently, if systems are to be measured by palæontological difference, the newer systems must include less thicknesses of rock.

But even when allowance is made for this, it is impossible to regard the divisions of Tertiary time introduced by Sir Ch. Lyell and given on p. 5 as being of the same relative importance as the systems of older date with which they are usually ranked. Even the Eocene, as understood by Lyell, was not of the same palæontological value as Cretaceous or Silurian, while the Miocene and Pliocene are still less entitled to rank with such systems. The Oligocene has been created at the expense of Lyell's Eocene, but it is now admitted that these two together form a group which may rank as a system, while the remaining three groups, Miocene, Pliocene, and Pleistocene, may be regarded as making up another system of deposits. For these two systems M. Hohnes has proposed the names *Palæogene* and *Neogene*, and though they are not altogether satisfactory the names have been largely accepted on the European continent.

Systems are divided into sections or formations, which are usually denominated as Upper, Middle, and Lower, unless any special names have been proposed for them. These sections are again divided into stages or groups, to which local names are generally given, and these again are often divisible into zones.

The following is a tabular view of the twelve fossiliferous systems which overlie the Pre-Cambrian rocks, together with their subdivisions of the first and second order, according to the nomenclature which will be adopted in this volume; the stages are mainly those of the British succession.

TABULAR VIEW OF THE SUCCESSION OF STRATA IN EUROPE

Systems.	Primary Divisions.	Groups or Stages.
Neogene	PLEISTOCENE	Recent Deposits.
		Valley and Cave Deposits.
		Glacial Deposits.
	PLIOCENE	Cromer Beds.
		Norwich Crag.
		Red Crag.
		Coralline Crag.
	MIOCENE	None in Britain.
Palæogene	OLIGOCENE	Upper (wanting in Britain).
		Middle, Hamstead and Bembridge Beds.
		Lower, Headon Beds.
	EOCENE	Upper, Barton and Bracklesham Beds.
		Lower, Bagshot Sands, London Clay, etc.
Cretaceous	UPPER	Upper Chalk (Senonian).
		Middle Chalk (Turonian).
		Lower Chalk (Cenomanian).
		Gault, etc. (Selbornian).
	LOWER	Lower Greensand (Vectian).
		Wealden and Neocomian.
Jurassic	UPPER	Purbeck and Portland Beds.
		Kimeridge Clay.
		Corallian and Oxford Clay.
	MIDDLE	Great Oolite Group.
		Inferior Oolite Group.
	LOWER	Upper Lias.
		Middle Lias.
		Lower Lias.
Triassic	KEUPER	New Red Marls.
		Waterstones.
	MUSCHELKALK	Absent in Britain.
	BUNTER	Upper Sandstone.
		Pebble Beds.
		Lower Sandstone.
Permian	UPPER	Magnesian Limestone (Zechstein).
	LOWER	Red Sandstones (Rothliegende).
Carboniferous	UPPER	Coal-Measures, Millstone Grit } Fusulina Limestones.
		Pendleside Group.
	LOWER	Carboniferous Limestone (Bernician).
		Shales and Sandstones (Tuedian).
Devonian	UPPER	Famennian.
		Frasnian.
	MIDDLE	Givetian.
		Eifelian.
	LOWER	Coblenzian.
		Gedinnian.

Systems.	Primary Divisions.	Groups or Stages.
Silurian	Ludlow Group	Upper Ludlow Beds.
		Lower Ludlow Beds.
	Wenlock Group	Wenlock Limestone.
		Wenlock Shale.
	Llandovery Group.	Tarannon Shales.
		Llandovery Beds.
Ordovician	Bala Series	Upper Bala and Ashgill Beds.
		Lower Bala and Caradoc Beds.
	Llandeilo Series	Upper Llandeilo.
		Lower Llandeilo.
	Arenig Series	Upper Arenig.
		Middle Arenig.
		Lower Arenig.
Cambrian	Upper	Tremadoc Slates.
		Dolgelly Beds.
		Ffestiniog Beds.
		Maentrog Beds.
	Middle	Menevian Beds.
		Solva Group.
	Lower	Caerfai Beds.

The preceding list of systems is merely a table from which no idea of relative thickness can be obtained, but the adjoining columnar view is drawn to scale and is intended to give some idea of the relative thicknesses of the systems which make up the Palæozoic and Neozoic divisions.

The actual thickness of any system of strata varies of course in different parts of the same country, and for the construction of the diagram, Fig. 1, the full average thickness of each stage has been taken from English districts where the whole system is well developed. The diagram does not, therefore, show the maximum thickness of any system. Moreover, in other parts of the world the Permian and Triassic systems are represented by marine deposits which reach a thickness of 9000 to 10,000 feet.

Further, the Neozoic division is much thicker on the European continent than it is in England, for in the Alps thick deposits come in between the Triassic and Jurassic systems, and the Neogene series is of much greater thickness in Southern Europe than it is in the north.

The Subdivision of Stages.—For the purposes of comparison and classification the smallest stratigraphical unit should be, not a single bed or stratum, but a bed, or set of beds, capable of palæontological definition. Such a unit is called a *zone*, but of course it is only possible to establish zones where there is a considerable thickness of fossiliferous beds. In the case of a thick mass of sediment without fossils, or containing very few fossils, such as the Old Red Sandstone and the English Trias, zones cannot be

established, and the units are only definable by their lithological characters.

A *zone*, as the name implies, is a belt or *band* of rock, that is, a certain thickness of beds characterised by a special assemblage of fossils, some of these fossils being either restricted to the band or particularly abundant in it. Moreover, it is not merely a specially fossiliferous band in a thick mass of sediment, but is one of a succession of zones, each stage in a fossiliferous series being usually divisible into two, three, or more zones.

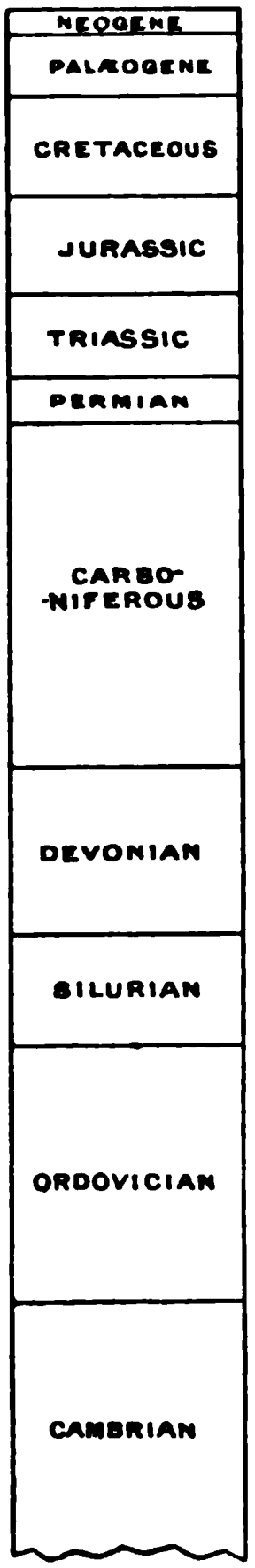

Fig. 1.—RELATIVE THICKNESS OF SYSTEMS. SC

The following remarks on zones are quoted from the author's memoir on the Cretaceous Rocks of Britain[1]: "By the fauna of a zone we generally mean all the fossils which have been or can be found in the beds which are recognised as belonging to the zone. But what may be termed the critical fauna of a zone is the much smaller assemblage of fossils which are either restricted to it or are specially abundant in it. One of these species is then chosen as the index of the restricted assemblage of species, and the name of this fossil is given to the zone, so that we speak of it as the zone of this fossil, *e.g.* the zone of *Ammonites varians*, or the zone of *Belemnitella mucronata*.

"The reader must be cautioned against becoming possessed with the idea that a zone is a set of beds characterised by the occurrence of one particular species, and that every bed which yields this index-species must belong to the zone. It must be remembered that this particular species is only one of several or many, and that it is this assemblage of species which is the guide to the zone.

"The value and importance of a zone depends partly on the number of restricted species and partly on the extent of country over which it can be traced. The thickness of a zone is of course a stratigraphical accident, depending merely on the amount of sediment deposited at any locality during the lifetime of the zonal fauna. Thus a zone may be in one area

[1] "The Gault and Upper Greensand," *Mem. Geol. Surrey*, vol. i. p. 34 *et seq.*

only a few feet in thickness, in another it may be 20 or 30 feet, and in a third it may expand into 200 or 300 feet.

"The limits of a zone may be definite or indefinite. Where sedimentation has been continuous and fairly rapid, the limits of the zones will naturally be indefinite; some of the characteristic species of one zone may survive into the overlying zone, and others which are characteristic of the latter may make their first appearance in the former. Thus in many cases it is impossible to say exactly where the one zone ends and the other begins, and though by careful collecting one may fix it with fair certainty in one section, one cannot be certain of taking exactly the same plane of separation in another quarry or cliff which is a few miles away from the first. Thus where a zone is complete its limits are indefinite, but the succession of zones will be the same in both places.

"Where a zone has definite limits it is generally because sedimentation ceased for a time, and in many cases because an erosive current swept away some of the sediment which had previously been accumulated, thus destroying the continuity of the record and producing what is called a "surface of contemporaneous erosion." Even if the current was only strong enough to prevent the accumulation of sediment, it causes a break in the record, because for a time there is no embedment and preservation of organic remains. In this way, therefore, a zone or a sub-zone may die out when traced in a certain direction."

In some cases still smaller zonal subdivisions may be recognised, consisting of one or two beds which are characterised by one or more peculiar species; these may be called *sub-zones* or *hemeræ*, but there is not necessarily a complete succession of such sub-zones, nor can they be expected to have so wide a geographical extension as zones; they are merely special horizons, and equivalent to the *niveaux* of French geologists.

CHAPTER IV

THE CORRELATION OF ROCK-GROUPS

SINCE organic remains afford such valuable aid in the task of classifying and correlating the different series of rocks which occur in different districts and countries, it is necessary that the geological student should become acquainted with the nature and proper use of palæontological evidence. In the present volume we are obliged to assume that the reader has some knowledge of biology, both recent and fossil, to the extent at least of knowing the appearance and general structure of the organisms included in the different classes and orders into which the animal and vegetable kingdoms are usually divided. We propose, however, to refer briefly to some of the facts connected with the geographical distribution of marine creatures.

Local Distribution.—Any one who has visited different places on the British coasts will not need to be told that the assemblage of molluscs and other sea-creatures to be found on the sea-shore is different at different places. Where the coast is rocky he finds a certain assemblage of species, but on the shore of a broad sandy bay he will find quite a different assemblage. Similarly if he hires a boat and a dredge he will find the creatures dredged from a rocky bottom will differ from those brought up from a sandy bottom, and both will differ from those obtained on a muddy bottom, though of course some species may occur on all three. Again, certain families of creatures, comprising many genera, such as the reef-building corals, live only in clear water, and would never be found alive where sand or mud was being deposited.

Confining our attention to the Mollusca, the following lists will illustrate what has been stated above. The genera mentioned under each head are those which prefer to live on such "bottoms," though some, such as *Tapes*, frequent both rocky and sandy bottoms.

Rocky.	Sandy.	Muddy.
Buccinum.	Nassa.	Corbula.
Purpura.	Natica.	Lutraria.
Litorina.	Cypræa.	Mya.
Patella.	Turritella.	Scrobicularia.
Arca.	Cardium.	Yoldia.
Tapes.	Tellina.	Solemya.
Venerupis.	Donax.	Gastrana.
Saxicava.	Mactra.	Panopæa.
Pholas.	Solen.	

Besides this distribution depending on the nature of the deposit which is being formed on the sea-floor, there is a further distribution according to the depth of water. The conditions of depth, including decrease of temperature, increase of pressure, and loss of light, produce a kind of zonal or vertical arrangement of species, some being only found near the shore, others in deeper water, and others again only occurring in the depths of the ocean. Even some genera have a restricted range within certain depths. This is termed the bathymetrical distribution of life.

The same conditions which regulate the local and bathymetric distribution of life-forms at the present time have regulated them in the past, and consequently when we are dealing with a group of stratified rocks, made up partly of limestones and partly of shales and sandstones, we find that many fossils occur in the limestones which do not occur in the shales, and that the sandstones contain other species which are not found in the other beds, because different creatures would live on the sea-bottoms where such different deposits were being laid down. Hence it might be thought that if a formation consisted in one district entirely of shale or limestone, and in another entirely of sandstone, the two sets of strata would contain such different assemblages of fossils that they might, on this principle, be regarded as belonging to two different systems, while in reality they were as nearly as possible contemporaneous. But, as a matter of fact, it is seldom that a natural group of rocks consists so entirely of one kind of sediment; the probability is that some beds of shale would be found in both districts, and that these shales, by their community of fossils, would establish the synchronism of the rocks with which they were associated. Moreover, there are generally a few species which are not so restricted in habitat, but occur both in the shaly and sandy sediments alike, having a wide range both in space and time; and such forms greatly assist in the work of correlation.

Zoological Provinces.—Besides the local and bathymetric distribution of species there is a further limitation of certain species, and even genera, to certain areas or regions, a restriction

for which differences of climate, food, and station are not sufficient to account. Contrast, for instance, the productions of tropical Africa and tropical America; and though there is a certain general similarity between them, in accordance with the similarity of climate, yet the differences are so great that it is clear some powerful influences have been at work to produce the results. The same conclusion would be arrived at by a comparison of the inhabitants of the sea on the eastern and western sides of North America, very few species being common to the Atlantic and Pacific shores.

The various forms of life are, in fact, so distributed over the earth that its surface can be mapped out into geographical regions or provinces to which certain groups of genera are confined. The boundaries of these provinces are sometimes well-marked, especially where any strong natural feature exists to act as a barrier and prevent migration from one area to another; a chain of lofty mountains, a wide expanse of ocean, or an isthmus of land separating marine provinces are such natural barriers.

The study of modern marine life is, of course, most useful to the geologist; but space would not allow us to indicate the distribution of the several classes of marine animals, even if full data were available, and it must therefore suffice to select the Mollusca as an example. In the distribution of the Mollusca seventeen marine provinces, exclusive of the Aralo-Caspian area, were recognised by S. P. Woodward, and adopted by Paul Fischer in 1887. These may be grouped as follows:—

1. Arctic zone--the *Arctic* province.
2. Cold Temperate zone—the *Boreal*, *Celtic*, and *Aleutian* provinces.
3. Warm Temperate zone—the *Lusitanian*, *Transatlantic*, *Californian*, and *Japonic* provinces.
4. Tropical zone—*West African*, *Indo-Pacific*, *Panamic*, and *Caribbean* provinces.
5. South Temperate zone—*South African*, *Australian*, *Peruvian*, and *Patagonian* provinces.
6. Antarctic zone—the *Magellanic* province.

In each of these provinces the majority of the species do not range outside the limits of the province, and in most of them there are certain genera which are restricted to the province. Thus the large Indo-Pacific province contains a number of genera which do not occur in any of the Atlantic provinces, no fewer than forty-five such genera being enumerated by Fischer.[1] On the other

[1] *Manuel de Conchyliologie*, 1887, p. 157.

hand, there are a certain number of Atlantic genera which do not occur in the Pacific or Indian seas.

The Australian province is another to which many genera are restricted, among these being *Risella*, *Bankivia*, *Struthiolaria*, *Amphibola*, *Chamostrea*, *Myodora*, and *Trigonia*.

Certain genera are specially characteristic of high latitudes, and curiously enough some of them occur both in the northern and in the southern hemisphere; such are * *Chrysodomus*, *Admete*, *Trichotropis*, *Trophon*, * *Margarita*, * *Yoldia*, *Cyprina*, * *Astarte*, *Mya*, and * *Crenella*, those to which an asterisk is prefixed occurring in both hemispheres.

Other genera are essentially tropical, the majority of their species living in the warm intertropical seas, with only a few species in the more temperate climes; such are *Conus*, *Harpa*, *Oliva*, *Voluta*, *Mitra*, *Cypræa*, *Spondylus*, *Plicatula*, *Perna*, and *Tridaca*.

Some Inferences from the Foregoing Facts.—A study of the modern distribution of life, whether in the sea or on the land, shows us that the provinces primarily depend on climate, and exhibit a tendency to arrange themselves in broad belts between the equator and the poles. This arrangement, however, has evidently been interfered with by the disposition of the continents, and the limits of the provinces are further narrowed or extended according to the union of the seas and continents. The spread of terrestrial life must depend on the present or past continuity of land, and especially on the connections in an east and west direction; the spread of marine life will depend on the extension of coast lines in the same direction.

The truth of the above remarks is well exemplified by considering the marine provinces on the western coasts of the Old and New Worlds respectively. Along the west coast of the New World we have the simplest possible arrangement of life regions, namely, a linear succession of provinces along a north and south coast line, and depending entirely on differences of climate. These provinces are (1) Aleutian, (2) Californian, (3) Panamic, (4) Peruvian, (5) Magellanic. The narrow isthmus of Panama prevents the union of the Panamic and Caribbean faunas which lie on each side of it; and if the coast of South America did not extend so far south, the Magellanic province would not exist, and the Peruvian would blend into the Patagonian.

Now let us turn to the Old World with its broken coast line; here the corresponding provinces are (1) Celtic, (2) Lusitanian, (3) West African, (4) South African, (5) (unpresented). The latitudinal extent of these areas is very different from the

American provinces; instead of being limited by a north and south coast line, the Celtic province spreads round England and eastward across the North Sea; the Lusitanian fauna likewise passes through the Straits of Gibraltar and stretches eastward as far as the Mediterranean Sea allows it. The West African is more limited, but the South African occupies eastern as well as western coasts.

It will be instructive next to consider what important effects on the distribution of life would be produced by some very slight changes in the geography of the world. Let us first suppose the isthmus of Panama and the southern extremity of South America to be submerged, and mark what would follow:—the Panamic and Caribbean provinces would no longer be separated; the Magellanic would disappear as a coast province (though some of the species would probably remain on the colder sea-bottoms), and the Peruvian and Patagonian would be merged into a province comparable with the South African.

On the other hand, if in the Old World we imagine England united to France, an isthmus of land raised across the Straits of Gibraltar, and the extremity of Africa prolonged southwards, we should then have an arrangement of life-provinces precisely like that which we now find along the west coast of America. The Celtic province would be limited to the west coasts of Britain and France, and the fauna of the North Sea would probably become more distinctly Boreal, the Lusitanian area would be similarly restricted, the Mediterranean becoming an inland sea, and its fauna being gradually differentiated from the Lusitanian; finally the prolonged extremity of Africa would become an Antarctic province comparable to the Magellanic, and would separate the eastern and western shores of south-temperate Africa, thus causing the development of two new provinces like the Peruvian and Patagonian of South America.

The above is not a mere fruitless exercise of the imagination, for we know that similar geographical changes have taken place in past times, and that such curtailments and enlargements of life-provinces must have occurred in consequence. We can even trace the operation of some such changes during the later periods of geological history. For instance, we have not to travel very far back in time before we come to a period when England was united to the Continent, and was then inhabited by many large mammalia which have since become extinct. Again evidence has been obtained which tends to show that in early Pliocene times the east and west coasts of England did belong to different life-provinces in consequence of the union of England with the Continent, and

that there was a considerable difference in the Molluscan faunas of the two areas.

The farther we go back in geological time the greater differences do we perceive in the distribution of the faunas, and the greater difficulty do we find in determining the limits of the life-provinces; but in comparing the fossils of the different members of the Tertiary and Secondary formations we must bear in mind that such provinces did undoubtedly exist, and that in tracing the rocks from one district to another we may at any time pass from the area of one province into that of another. When we reach the Primary rocks there is some doubt as to the existence of very definite life-provinces, which seem at any rate to have been fewer, and consequently more extensive than those of later periods.

The wide range of certain Palæozoic species suggests that there was a time when the same marine fauna ranged over the whole world, and that it was only as time went on that genera became limited to certain portions of the earth's surface; the modern life-provinces being the outcome of local differentiation, and of the circumstances which have retarded or accelerated the progress of development from time to time.

Synchronism and Homotaxis.—It was stated in Chapter I. that when two districts are physically separated from one another we have to rely entirely on community of fossils in comparing the rocks of the one with those of the other; and if the rocks so compared were deposited originally within the limits of the same life-province, the groups which contain similar assemblages of species may safely be regarded as contemporaneous.

To take an example, no one would hesitate to correlate the members of the Ordovician and Silurian systems in North Wales and the Lake District by means of the fossils they contain, because there is every reason to suppose that the two districts formed part of the same province during those periods. Similarly the members of the Lower Cretaceous series in the Isle of Wight and in the Weald may be correlated with some degree of exactitude; but the same group of beds in Lincolnshire contains such a different set of fossils that it obviously belonged to a different life-province, and it is impossible to indicate the exact equivalents of the several members of the southern series.

Again, when we come to compare districts at a still greater distance from one another—as, for instance, Wales and Bohemia, Sussex and the South of France, or England generally with North America—we find that there is certainly a general resemblance in the vertical succession of faunas which have flourished in the respective areas, *i.e.* the rock-series in each country can

be divided into groups, which are characterised by the presence of the same genera; but the species are different, and it would be a mistake to conclude that portions of formations containing assemblages of the same genera in countries so far apart were contemporaneous in the same sense as the members of the Silurian series in Wales and Cumberland are contemporaneous.

A group of species originating in one locality and spreading along the coasts of a continent would take a long time to travel from Europe to America even if there were continuous coast lines. Sometimes their progress would be arrested for a time, until physical or geographical changes allowed them to advance; at other times they would make their way by accommodating themselves to varying conditions and by throwing out collateral varieties. The date of their first appearance in one part of the world would be very much in advance of their arrival in the other, so that the fact of two distant formations containing fossils of closely allied species can be no proof of their being really contemporaneous.

It is certain, however, that in every part of the world the geological sequence discloses the same general succession of life-forms. The progress of development may have been retarded here and accelerated there, but the successive fossil assemblages are similar to one another, and the order in which they occur is the same all over the world. We never find a Carboniferous fauna antedating a Silurian or Devonian fauna, though we may find the first succeeding the second without the presence of the intermediate Devonian assemblage. This common order of succession has been termed *Homotaxis*, and the Silurian system of Britain is spoken of as *homotaxial* with and equivalent to the Silurian of America; even the larger subdivisions of the one may be paralleled with those of the other, as homotaxial equivalents or representatives, so that we may speak of the Niagara group as equivalent to the Wenlock Beds, understanding by this that the groups are homotaxial equivalents and not absolutely coeval formations.

To sum up the preceding observations, the occurrence of the same assemblage of species at different localities may be taken as evidence that the beds containing them are of the same age, and were formed at the same time. Again, a knowledge of the general succession of generic forms enables us to fix the relative age of any set of fossils, and, consequently, the homotaxial position of the beds containing them. In other words:

1. Assemblages having many species in common may be regarded as contemporaneous.
2. Assemblages having many genera in common may be regarded as homotaxial equivalents.

CHAPTER V

THE LITERATURE OF HISTORICAL GEOLOGY

It has been suggested to me that some information as to the principal geological publications and as to the facilities which exist for ascertaining what has been published about any particular system or series of beds would be useful to the student.

During the first half of the last century, and indeed up to about the year 1860, publications on stratigraphical geology were comparatively few, and it was possible for any geologist to have a fair acquaintance with all that had been written on the subject; but as time went on the number of workers increased, and more numerous additions were made every year to our knowledge of British rocks and fossils, as well as of their equivalents in other countries.

Every year added a volume to the publications of the Geological Societies of London, Edinburgh, Glasgow, Manchester, and other centres, to the volumes of the Palæontographical Society, and of the *Geological Magazine*. The Geological Survey also have issued a long succession of maps and memoirs, most of which have appeared within the last forty years.

At the present day, therefore, it is almost impossible for any one to make himself acquainted with all that has been written on the stratified rocks of Great Britain, and quite impossible to have at the same time a good knowledge of the fossils which they contain. Consequently in these branches of geology, as in the case of other sciences, the tendency is toward the specialising of knowledge. After the student has acquired a certain amount of knowledge about the successive geological systems and their characteristic fossils, he probably becomes specially interested in one of them, or in the rocks which occur in some particular district, and then he wishes to know in what books and memoirs accounts of that series of rocks or of that particular district have appeared.

The descriptive parts of this volume contain only the more

important facts respecting each system of rocks. The book is designed to include only so much information about each great series of stratified deposits as the student may be expected to read and to have before him for constant reference. Descriptions with a certain amount of detail will be given of the more important districts in the British Islands where each series is well developed and exposed, but the Irish rocks will be treated in less detail than the English, and those of the European continent will be still more briefly mentioned, except in certain cases where they present us with formations or special facies not to be found in the British Isles.

But the task of selecting information from the great mass of detail which has now been accumulated is not an easy one, and further, what is regarded as specially important in one part of the country may seem of less importance in another part, for naturally each teacher will wish his pupils to become specially acquainted with the rocks of the country or district in which they live. I propose, therefore, in this chapter to indicate briefly what are the most important and useful publications, how they can be obtained, and how they should be used, in order that the reader may learn how to extend his knowledge of any particular series of rocks, or to find out what has been published about the geology of any special district.

The publications may be grouped under four heads—Maps, Stratigraphy, Palæontology, Palæogeography.

Maps

It is necessary that the student should have access to a geological map of the British Islands. Every teacher will doubtless see the necessity of exhibiting one in his lecture-room, but every student should as soon as possible acquire one for himself. Unfortunately a good cheap geological map of the British Islands as a whole is yet a desideratum, but there are two good ones for those who can afford them, and several separate maps of England, Scotland, and Ireland, besides the detailed maps of the Geological Survey.

The following general maps may be recommended :—

1. Geological Map of the British Islands, by Sir A. C. Ramsay in four sheets. Scale 11½ miles to an inch (Stanford). Price 32s. In case 42s.
2. Geological Map of the British Islands, by E. Best, from Stanford's London Atlas, purchasable separately for 10s. 6d.
3. The Geological Survey Index Map of England and Wales.

in 13 sheets, on the scale of 4 miles to an inch, with index of colours. Price of each sheet 2s. 6d. Particulars obtainable from Mr. E. Stanford.

4. Geological Map of England and Wales, by Sir A. C. Ramsay. Scale 11 miles to one inch. (Stanford). Price 25s. In case 30s.
5. Geological Map of England and Wales, by H. B. Woodward and J. G. Goodchild (Philip and Son). Scale 17 miles to an inch. Price 5s. In case 7s. 6d.
6. Geological Map of England and Wales, by Sir A. Geikie, (Stanford). Scale 10 miles to one inch. Price 10s. In case 14s.
7. Geological Map of Scotland, by Sir A. Geikie. Scale 10 miles to an inch (Stanford). Price 6s. Mounted in case 10s.
8 Geological Map of Ireland, by E. Hull. Scale $7\frac{3}{4}$ miles to an inch (Stanford). In two sheets. Price 25s. In case 30s.

If maps of a special district are required the reader should write for a catalogue of the maps issued by the Geological Survey of the United Kingdom, this catalogue being obtainable from Mr. E. Stanford, Long Acre, London ; or from J. Menzies and Co., Edinburgh and Glasgow, or from Hodges, Figgis, and Co., Dublin.

Besides the index map above mentioned the Geological Survey issues two sets of maps on the scale of one inch to a mile, one being known as the "Old Series," the other as the "New Series." The publication of the Old Series is completed, and any sheet can be obtained. The price of the large sheets (coloured geologically) is 8s. 6d., but those which are divided into quarter-sheets are 3s. per quarter sheet, and a few along the sea-board are only 1s. 6d. Many of these maps are also issued in two forms, one showing the superficial deposits or "Drift," the other "without Drift," and in ordering it should be stated which is desired.

The New Series is in course of publication, and is issued in sheets of a uniform size at prices varing from 1s. 6d. to 3s. 6d., most of them being 3s. Of these also there are in most cases two editions, one with Drift and one without

Stratigraphy

It will be convenient to mention first those books and memoirs which are of a general nature but yet give more information about certain formations than will be found in this volume.

Among these are *The Geology of England and Wales*, by H. B. Woodward (second edition, 1887; third in preparation). This book contains specially full accounts of the Jurassic and Cretaceous systems, and of the Pleistocene and Recent deposits, and has a good geological map. (Philip and Son.) Price 16s.

Manual of the Geology of Ireland, by G. H. Kinahan (1878). With a geological map. Kegan Paul and Co. Price 12s.

The Coal-fields of Great Britain, by Professor Hull, gives general descriptions of the strata which constitute the Upper Carboniferous series in all parts of Great Britain. (Stanford.) Price 16s.

The Physical Geology and Geography of Ireland, by E. Hull (second edition, 1891), with a small geological map of Ireland. Price 7s. 6d. (Stanford.)

The Geology of the Country around Liverpool, by G. H. Morton (second edition, with Appendix, 1897). G. Philip and Son.

With respect to the foreign equivalents of British rocks brief but good descriptions will be found in Sir A. Geikie's *Text-book of Geology* (third edition, 1893), also in the *Text-book of Comparative Geology* by Messrs. Kayser and Lake (1895), and in De Lapparent's *Traité de Géologie* (fourth edition, 1900).

The Geological Survey has published the following memoirs, which deal either with special formations or with districts of considerable size and importance :—

The Geology of North Wales, by Sir A. Ramsay, second edition (1881). Price 21s.

The Geology of the Southern Uplands of Scotland, by B. N. Peach, J. Horne, and others (1900). Price 10s. 6d.

The Geology of the Yorkshire Coal-field, by A. H. Green and others (1878). Price 42s.

The Geology of North Derbyshire, by A. H. Green and others, (1887). Price 5s. 6d.

The Geology of the Burnley Coal-field, by E. Hull and others (1875). Price 12s.

The Geology of the Bristol and Somerset Coal-field, by H. B. Woodward (1876). Price 18s.

The Triassic and Permian Rocks of the Midland Counties of England, by E. Hull (1869). Price 5s.

The Geology of the Weald, by W. Topley (1875). Price 17s. 6d.

The Geology of the Isle of Wight, by C. Reid and A. Strahan (1889). Price 8s. 6d.

The Geology of the Isle of Purbeck and Weymouth, by A. Strahan (1898). Price 10s. 6d.

The Geology of London and of Part of the Thames Valley, by W. Whitaker, in two volumes (1889). Price 11s.

Guide to the Geology of London and Neighbourhood, by W. Whitaker, fifth edition (1889), sixth in press. Price 1s.

The Jurassic Rocks of Britain—

Vol. I. Yorkshire, by C. Fox-Strangways (1892). Price 8s. 6d.

Vol. II. Yorkshire, by C. Fox-Strangways. Tables of Fossils. Price 12s.

Vol. III. The Lias of England and Wales, by H. B. Woodward (1893). Price 7s. 6d.

Vol. IV. The Lower Oolitic Rocks of England, by H. B. Woodward (1894). Price 10s.

Vol. V. The Middle and Upper Oolitic Rocks of England, by H. B. Woodward (1895), with Bibliography of Jurassic Literature. Price 7s. 6d.

The Cretaceous Rocks of Britain—

Vol. I. The Gault and Upper Greensand, by A. J. Jukes-Browne (1900).

Vol. II. The Chalk of England, by A. J. Jukes-Browne, with a Bibliography of the Cretaceous Literature. In the press.

The Pliocene Deposits of Britain, by C. Reid (1890). Price 5s. 6d.

A list of the smaller or more local memoirs (explanations of various sheets of the one-inch map) will be found in the Catalogue of Maps and Memoirs mentioned on p. 36. Many of them have lists of the publications referring to the district under description.

The next most important source of information is the *Quarterly Journal of the Geological Society of London*, the publication of which commenced in 1845. There is an excellent index to the first fifty volumes of this Journal, which can be purchased from the Geological Society, Burlington House, London (price 10s.) This index gives references to the names of authors, of places, and of subjects, so that by its means it is easy to ascertain what papers have been published in the Journal on any particular area or any set of beds. This index deals with the yearly volumes between 1845 and 1894.

The Geological Society also publishes every year a list of the various items of geological literature which have been added to its library. This publication began in 1894, with a list for the latter half of that year (price 1s.) Each succeeding annual part is issued in a paper cover (price 2s.), and is divided into two portions, the first being an index of authors' names with titles of papers, and the

second an index of subjects, and each separate paper in all the publications purchased or received by the Geological Society is entered in these indices, as well as all the papers published in the *Quarterly Journal* of the Society since 1894. It will be seen, therefore, that this annual list forms a fairly good index to the geological literature of the whole world.

Before this work was taken in hand by the Geological Society of London two attempts had been made in England to establish an annual record of geological literature. These were :—

1. The *Geological Record*, consisting of six annual volumes (1874-1879), edited by W. Whitaker, giving short abstracts of all papers, British and foreign ; and two volumes (for 1880 to 1884 inclusive), edited by W. Topley, giving titles only. Published by Taylor and Francis, London. Price 16s. per volume.
2. The *Annals of British Geology*, by J. F. Blake (Dulau and Co., London). Four volumes (1890-1893). Price of the vol. for 1890, 5s., of others, 9s. This gives abstracts of all the books, memoirs, and papers on British geology published during those years, under separate heads.

The volumes of the *Geological Magazine* contain many articles on stratigraphical geology, but unfortunately there is as yet no general index to this publication. It commenced as the *Geologist* in 1858, was changed to the *Geological Magazine* in 1864, and is published in monthly parts (price 1s. 6d. each part). It is to be hoped that a general index to all the volumes from 1858 to 1894 may be prepared and published before long.

The Geologist's Association publishes *Proceedings* which contain many useful papers, and each volume contains the proceedings and communications of two years, with accounts of excursions and a good index. The first volume is for the years 1868-69. The Association has also published a *Record of Excursions* from 1860 to 1890, price 12s. 6d. (Stanford), which contains many sections, maps, and illustrations.

Of the provincial societies which publish geological papers the chief are the following :—the Geological Societies of Edinburgh, Glasgow, Manchester, and Liverpool, the Yorkshire Geological and Polytechnic Society, and the Royal Geological Society of Cornwall.

Particulars respecting the above and all other scientific societies in the United Kingdom will be found in the *Official Year-Book of Scientific and Learned Societies*, published by C. Griffin and Co., Strand, London. Price 7s. 6d. each annual volume.

The British Islands have been the scene of repeated volcanic eruptions, and volcanic products are interbedded with the sediments of all the Palæozoic systems, except perhaps the Permian. Brief descriptions of the contemporaneous volcanic rocks will be given in the following pages after that of the sedimentary rocks of each period, but the reader will find this part of the subject admirably treated by Sir Archibald Geikie in his *Ancient Volcanoes of Great Britain* (Macmillan and Co., 2 vols. 1897, price 36s.)

Palæontology

For the proper study of historical geology it is essential that the student should have some knowledge of the forms and structure of the different classes of animals, and especially of the Invertebrate classes. This general acquaintance he can get from a careful perusal of Mr. H. Woods's small manual of Palæontology in the Cambridge Natural Science Series (second edition, 1899, price 6s.), but he may sometimes find it necessary to refer to larger books on the subject. Of these the best are :—

A Manual of Palæontology, by Messrs. Nicholson and Lydekker, third edition, in two volumes (1889), price 42s.

Zittel's *Text-book of Palæontology*, the American edition of 1900, published by Macmillan and Co., vol. i., price 25s.

Outlines of Vertebrate Palæontology, by A. S. Woodward, Camb. Univ. Press, price 14s.

Besides these may be mentioned a series of volumes now being issued under the title of *A Treatise on Zoology*, edited by Professor E. R. Lankester, and published by A. and C. Black. Four of these volumes have been, or will shortly be, published, describing : I. The Protozoa ; II. The Porifera and Cœlenterata ; III. The Echinoderma ; IV. The Mesozoa. Price of each part 10s. Fossil forms are dealt with in some of them.

The stratigraphical geologist, however, has to deal with fossils principally as important aids in determining the relative age of rocks, and he has therefore to make himself acquainted with the fossils which are most characteristic of the different systems, and especially with those species which have a restricted range within each system and thus characterise stages and zones.

Lists of characteristic fossils will be given in this volume, together with figures of some of them. The student will, however, be glad to know where he may find figures of other species, and he may consult the following books with advantage:—

For Palæozoic fossils a useful book is Baily's *Characteristic British Fossils*, vol. i., with 42 plates (1875). Copies of this can

still be obtained from Messrs. Dulau and Co., 37 Soho Square, London. Price 10s.

For Tertiary fossils Lowry's *Chart of Characteristic Tertiary Fossils* can be recommended (Stanford. Price 4s.)

For fossil Crustacea Woodward and Lowry's *Chart of Fossil Crustacea* is good, though not limited to British species.

The figures in Kayser's *Text-book of Comparative Geology* (English edition, Sonnenschein and Co., 1895) are very good and numerous, and though some of the species are not British, a large number are both British and Continental.

The more recent memoirs of the Geological Survey—that is to say, most of those published since 1890—contain figures of some of the characteristic fossils of the formations described. The memoirs on the Jurassic rocks and on the Cretaceous rocks may be specially mentioned as containing many figures of fossils that will be useful to the student.

For illustrations of fossil plants and for information on their structure and affinities Seward's *Fossil Plants* should be consulted (Cambridge Nat. Science Manuals, two volumes, price 12s. each). *Studies in Fossil Botany*, by D. H. Scott (A. and C. Black), is also excellent.

As works of reference which ought to be found in every library of scientific books the publications of the Palæontographical Society must be mentioned, for these volumes are the great storehouse of illustrations of British fossils. The annual quarto volume of the Society costs only 21s., and contains parts of four or five monographs, with from thirty to forty plates. The Society was established in 1847, and a list of the monographs which have been completed and of those which are in progress can be obtained from Messrs. Dulau and Co. (Soho Square, London). The completed monographs can be purchased separately, and include monographs on Fossil Corals, Echinoderms, Brachiopoda, Trilobites, Devonian Fossils, Mollusca of the Crags, and Ammonites of the Lias.

Another work of reference is Etheridge's *Fossils of the British Isles*, vol. i. (Clarendon Press, Oxford, 1888), which is a complete list of the fossils recorded from the Palæozoic rocks of Britain up to that year, showing the range of each species.

Palæogeography

The geography of the earth's surface has gone through a long series of phases and mutations. Each period may be said to have had a geography of its own, but the special phase with which it opened slowly changed toward the evolution of the ensuing phase

by the upheaval of one region and the subsidence of others, or by a general regional movement of elevation or subsidence. Sometimes indeed great changes seem to have taken place within the duration of a single period. The present arrangement of land and sea, as well as their relative heights and depths, is merely the last of these phases, but it is at the same time a result of the geographical evolution which has been in progress ever since the earth's crust was cool enough for water to condense and settle upon it; in other words, modern geography is the outcome of all the past geographical changes.

The restoration of ancient phases of geography, the attempt to indicate the limits of the seas and the positions of the land areas of any age or period is one of the most difficult problems that a geologist can endeavour to solve. Shore-lines are seldom preserved, and the essay involves a careful consideration of the conditions under which various local deposits have been formed, and a studied use of the scientific imagination in estimating the original extension of deposits, of which only small portions are in many cases preserved or exposed.

Such endeavours to restore the geographical conditions of past periods must at present be tentative, and with respect to the older periods they are probably more suggestive than real; but they exercise the faculty of inductive reasoning, and they help to show the student that there are aims and objects to be attained by the study of historical geology which are more interesting than the mere enumeration of rock-groups or the recognition of characteristic fossils.

Brief indications of the probable positions of the land areas and of the conditions under which the rocks were formed are appended to the description of each period; but for more detailed considerations of the various points involved the reader is referred to the author's treatise on the *Building of the British Islands* (second edition, 1892, Bell and Sons), and to Professor Hull's *Contributions to the Physical History of the British Isles* (1882, Stanford). He will also find maps that deal with a wider area in the last edition (fourth) of De Lapparent's *Traité de Géologie* (1900).

CHAPTER VI

PRE-CAMBRIAN SYSTEMS

THE geological history of Britain opens with a chapter the pages of which are so tattered, blurred, and defaced by the ravages of Time, that their characters are hardly decipherable, and the record is differently interpreted by different experts. Moreover, to continue the simile, this chapter is incomplete both at the beginning and at the end, so that we know not how many pages preceded those we possess, or how many succeeding pages have been torn out and destroyed, for the pages of our history are not numbered. We only know that some are wanting, and that there is a gap, unfilled as yet by the history of any other country, between this first dim and ancient record and the better preserved chapters which succeed it.

In more scientific and matter-of-fact language, there are certain parts of the British Isles where the Cambrian rocks to be described in the next chapter rest on a still older series of rocks. Most of these Pre-Cambrian rocks are crystalline and foliated—gneisses and schists; some, however, are clearly of sedimentary origin—slates, sandstones, and conglomerates, while others are as distinctly of volcanic origin—lavas, ashes, and agglomerates. All, however, are now everywhere more or less cleaved and indurated. For these ancient rocks Dana's name of Archæan is sometimes used, but as many writers prefer to restrict it to the crystalline schists, and as the term Eparchæan has been proposed for the sedimentary series, it will be best to employ the simple name of Pre-Cambrian as a convenient designation until the several systems have been more thoroughly investigated. With these Pre-Cambrian rocks are included some which were previously considered as Cambrian.

With the exception of worm-tracks no fossils have yet been found in undoubted British Pre-Cambrian rocks, but some impressions resembling those of a Trilobite and others which may belong to *Lingulella* have been obtained from the slates of the Longmynd,

and it is stated that similar rocks in North America have yielded a few Brachiopods and Lamellibranchs. Certain Archæan limestones, moreover, in Canada and in Bavaria contain some curious structures which have been described as organic under the name of *Eozoon*, but this view is not generally accepted, and the most prevalent opinion is that the so-called *Eozoon* is a peculiar mineral structure which simulates that of certain Protozoa. The material consists of alternating layers of calcite and serpentine.

The Pre-Cambrian rocks present us with a great variety of petrological material. Those which appear to be the oldest, at any rate in Britain, consist mainly of coarsely crystalline gneisses and schists, associated with intrusive masses of igneous rock (granites, syenites, diorites, etc.) Above these there are in some areas rocks which are clearly of sedimentary origin (slates and grits) associated with igneous rocks, both contemporaneous and intrusive, but all more or less schistose and metamorphosed. In other areas there are comparatively unaltered stratified deposits associated with contemporaneous volcanic rocks (lavas, ashes, and tuffs). This last group appears to be the highest and therefore the newest of the several divisions or systems. It is, however, impossible at present to arrange the British Pre-Cambrian rocks in a definite order of succession, because they occur in several isolated areas which are difficult to compare with one another, and the triple subdivision based upon degrees of alteration has not yet been made out in any one area, though in several there is a very clear division into two series or systems.

The following are the principal areas in the British Isles where rocks occur that are clearly or presumably older than the Cambrian: (1) Scotland (Hebrides and N.W. coast); (2) Ireland (Donegal, Londonderry, Mayo, and Galway); (3) South Wales (Pembrokeshire); (4) North Wales (Anglesey and Caernarvon); (5) Shropshire; (6) Warwickshire and Leicestershire; (7) The Malvern Hills; (8) Cornwall.

The student cannot be expected to make himself acquainted with the structure and stratigraphical details of all these areas, and we shall therefore confine our attention to those localities which present us with the principal types of Pre-Cambrian rocks. It will be convenient to commence with Scotland, where the most highly metamorphic rocks are finely displayed and are succeeded unconformably by a little altered series of sediments. A brief account of the Irish Pre-Cambrians will then be given, followed by a fuller description of those on Wales and Shropshire and brief references to the other areas.

Stratigraphy

1. *Scotland*

The whole of the Outer Hebrides (Lewis, etc.) and large parts of Sutherland and Ross consist of Archæan rocks. These are divisible into two very different groups or systems—a lower set of crystalline and gneissic rocks, and an upper series of red sandstones and conglomerates, which rest unconformably upon the former. The rocks of this region were first described in 1819 by MacCulloch, who recognised the unconformity between them, but not the true age of the sandstones. They were subsequently described by Sharpe, Nicol, and Murchison,[1] between 1852 and 1861; still later by Hicks, Bonney, Callaway, and Lapworth,[2] and in 1883 the mapping of the district was undertaken by the Geological Survey, with results published in 1888.[3 a]

(1) *The Gneissic Group.*—This was termed by Murchison in 1859 the Fundamental or *Lewisian* gneiss, and the name *Hebridean* has also been applied to it. The following description is taken mainly from the account published by the Geological Surveyors in the paper above referred to.

The so-called gneisses or gneissic schists are well-exposed in the cliffs between Cape Wrath and Loch Torridon. They present two types of structure, appearing in some parts as "massive rudely-foliated crystalline rocks, with few divisional planes, or [in other parts] as well-banded gneisses in which the constituents have a distinct parallel arrangement. Both varieties are traversed by segregation veins and pegmatites. The prominent minerals are plagioclase felspar, pyroxene, hornblende, quartz (frequently opalescent) and magnetite. It is worthy of note that mica is a rare constituent of these original types of gneiss. On close examination it is apparent that the bands present certain lithological varieties of variable thickness, some consisting mainly of pyroxene or hornblende and a small quantity of plagioclase felspar, some of plagioclase, pyroxene (or hornblende), and opalescent quartz, others of opalescent quartz and felspar. These varieties frequently cross the lines of schistosity, and are evidently due to differences in the nature of the materials prior to the development of the foliation."

In some places these foliated rocks include masses of non-foliated basic igneous rock (gabbros, peridotites, augite-granulites, and diorites), arranged in lenticular belts which are more or less paralleled to the foliation. These patches and belts are intersected by veins of gray pegmatite, consisting mainly of felspar and quartz, and varying in thickness from a few inches to several

[a] References will be found at the end of the chapter.

yards. But when these non-foliated masses are carefully traced it is found that they pass laterally into the rudely foliated basic gneisses and that the pegmatites merge into quartz-felspar schists. Hence it is concluded that almost the entire mass consisted originally of igneous rocks, and that the gneisses have been developed out of the igneous complex by the mechanical stress and deformation consequent on very great subsequent movements of the earth's crust in this region.

This conclusion is in contrast to the earlier idea that the gneisses were sedimentary rocks which had been converted into foliated rocks by such metamorphic processes. Under this older view estimates of thickness were sometimes ventured upon, but under the newer view the thickness or depth of the gneissic mass is of little importance. It should be mentioned, however, that the banding of the gneisses simulates a bedded structure, and that these bands have been bent into gentle flexures (anticlinal and synclinal), the axes of which usually strike from N.E. to S.W. There is also a secondary and more minute plication of the gneisses into folds which trend E. and W. or N.W. and S.E., and this has evidently been produced by earth movements that took place after, and probably long after, the development of the first foliation, but prior to the final foliation.

The history of these gneissic rocks appears to have included several stages or epochs, which are tabulated as follows :—

1. The irruption of a great series of igneous rocks.
2. The development of crust-pressure and mechanical movements which produced a foliation of the igneous rocks.
3. The intrusion of a second series of igneous rocks.
4. Further crust-pressures of enormous power, crushing and breaking up the whole complex, and producing thrust-planes, together with a secondary foliation and a secondary plication of the gneisses.
5. The final foliation of the gneisses and pegmatites.

A further remarkable point is that all these processes were accomplished before the formation of the overlying Torridon sandstone, which is not affected by them.

The extraordinary succession of disturbances—eruptive, disruptive, and metamorphic—to which the Lewisian gneiss has been subjected is not yet exhausted, for it appears that there was another period of intense crust-pressure in post-Cambrian time. This of course affected all the rocks from the highest Cambrian downward. As might be supposed, the fundamental Lewisian gneiss underlies all the eastern part of Sutherland, and in that district there are huge slices and masses of such rock which have been driven along thrust-

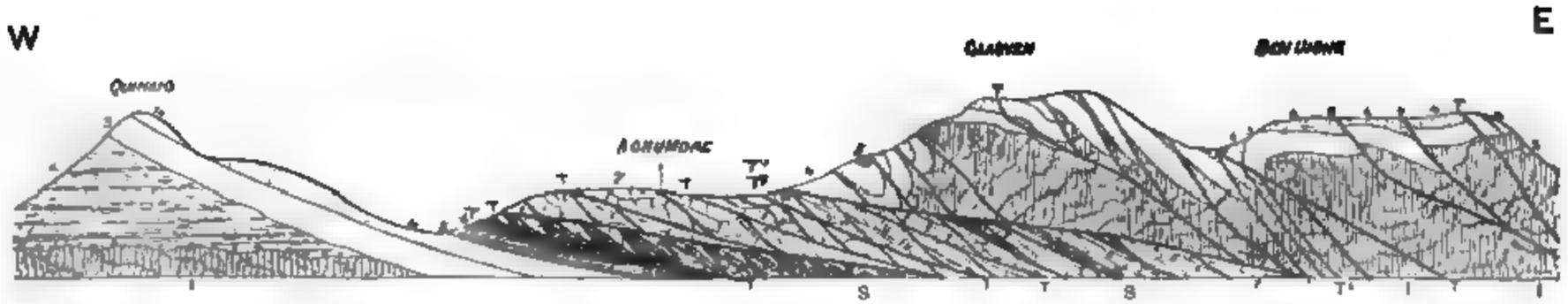

Fig. 2.—SECTION FROM QUINAIG ABOVE LOCH ASSYNT TO GLASVEN AND BEN UIDHE (from *Quart. Journ. Geol. Soc.* vol. xliv. p. 418, by permission). Distance about 6 miles.

7. Durness limestone
6. Serpulite grit
5. Fucoid beds
4. Upper quartzite
3. Lower quartzite
} Cambrian.

2. Torridon sandstone
1. Lewisian gneiss
} Pre-Cambrian.

T. Thrust-planes represented by black lines.

S. Bands compounded of Durness limestone, serpulite grit, and Fucoid beds repeated by minor thrust-faults.

Fig. 3.—SECTION ACROSS THE LONGMYND AREA IN SHROPSHIRE. Distance about 8 miles.

S. Silurian.
O. Ordovician.

D. Shineton shales.
C. Comley sandstone.
} Cambrian.

1 to 8. Longmyndian series.
A. Uriconian rocks.
} Pre-Cambrian.

FF. Faults.

planes for many miles, and often now overlie tracts of Cambrian strata; in other words, the Cambrian and Pre-Cambrian rocks have been broken up into slices, and these slices have been driven over one another along the planes of disruption, which are known as thrust-planes or thrust-faults. Some idea of the complicated structure thus produced may be gathered from a study of Fig. 2, which is taken from the Report above quoted. Such being the real structure of the district, the reader will hardly be surprised to learn that the order of superposition was not understood by the earlier observers, and that a great controversy raged for many years with respect to the age and position of the eastern gneisses and schists.

(2) *The Torridonian.*—Between the formation of the Lewisian gneisses and that of the overlying sandstones and conglomerates there must have been a very long interval of time. The gneissic rocks were apparently raised into dry land and subjected to much sub-aerial erosion and detrition, for the unconformity between them and the Torridon sandstone is a very marked one. In some places the surface of the gneiss is a nearly level or gently-inclined plane, but in Assynt it was carved into a series of dome-shaped eminences, and in one case a hill of Lewisian gneiss, about 700 feet high, projects through the lower part of the Torridonian series, and successive members of this series overlap one another on its slopes.

In Assynt the total thickness of the Torridon sandstones is from 3800 feet to 4000 feet, but farther south higher beds come in and the whole series is thicker, amounting in the Loch Broom district to more than 8000 feet. Here it has been divided by Messrs. Peach and Horne into the following groups[4]:—

Groups.	Nature of Materials.	Thickness.
4. Cailleach Head group	Sandstones, flags, dark shales, and calcareous bands	1000 to 1500
3. Aultbea group	Chocolate-coloured sandstones and flags with gray flags and partings of shale	2000 to 3000
2. Applecross group	Coarse arkose with pebbles of quartz, quartzite, etc.	4000 to 5000
1. Diabeg group	Red sandstones and mudstones with gray grits and black shales and calcareous bands	500 and upwards

Still farther south in Skye Mr. Clough finds that the lowest or Diabeg group expands in a remarkable way, and that if there

is no undetected reduplication by folding, it alone must be between 5000 and 6000 feet thick. He divides it into four sub-groups, the lowest of which consists mainly of epidotic grits or arkose with abundant pebbles of epidotised felspar; thin bands of greenish shale occur in these grits, and on the mainland there is a basal conglomerate resting on the gneiss (Rep. cit. for 1893).

Small patches of Torridonian sandstone occur in the island of Lewis, and show that the series had a western extension; outliers of it have also been detected beneath the Cambrian rocks of East Sutherland, so that it must originally have occupied a very large area, and probably extended beyond the shores of Scotland both on the east and on the west. It was, however, to a large extent destroyed and broken up into isolated tracts during the time which elapsed before the deposition of the lowest Cambrians.

The north of Scotland thus presents us with two great Pre-Cambrian formations and two great unconformities.

(3) *The Dalradian Complex.*—The formations above described appear to be confined to the north and north-western parts of Scotland, passing south-westwards into Skye and the west of Inverness, but there is another large region of metamorphic rocks, that of the Central Highlands, with the Grampian Mountains as its centre, a region comprising all Inverness east of the Great Glen, with large parts of Elgin, Nairn, Aberdeen, Perth, and Argyle. A large proportion of the rocks in this area consist of sediments which have been converted into schistose rocks of various kinds, with massive quartzites, phyllites, and some important bands of limestone; there are also rocks which may be altered and foliated lavas and tuffs.

The relative age and positions of these rocks have not yet been definitely worked out. They may be partly of Torridonian and partly of Cambrian age, but they may include strata formed during one or both of the periods represented by the two great breaks above mentioned as existing in the northern succession, and it is also possible that some Ordovician beds may be entangled along the southern border of the complex. The region is under examination by the officers of the Geological Survey, who will doubtless be able before very long to establish the age of some of the members of this great complex.

Meantime Sir A. Geikie has proposed the name *Dalradian* as a temporary designation for this great group of schistose rocks, merely as he says "to provide a convenient descriptive epithet which shall be precise and save periphrasis."

2. *Ireland*

In the north-western part of Ireland there are two districts which present many features resembling those of the Scottish Highlands. Their geographical position is that which a prolongation of the Central Highlands would occupy on the same line of strike, and as the island of Islay and the long promontory of Cantire consist of similar rocks there can be little doubt that the north-west of Ireland is actually a physical and structural continuation of the Grampian Highlands.

Tracts of granitoid gneiss occur in the west of Donegal, on the west coast of Mayo, in the Ox Mountains near Pomeroy in Tyrone, and in the west of Galway. Associated with these gneisses are large areas of more or less metamorphosed sedimentary rocks, a series of mica-schists, quartz-schists, quartzites, phyllites, and limestones which closely resemble the Dalradian series of Scotland. Dr. Callaway has examined a part of the series in Donegal and believes that it can be divided into two portions, an older series of highly metamorphosed rocks and a newer series of hypometamorphic or less altered sediments.[5] A more recent and comprehensive account of the Irish Pre-Cambrian rocks has been published by Sir A. Geikie,[6] and still more recently Mr. M'Henry has discovered the base of the Dalradian group near Castlebar in Mayo with a basal conglomerate resting on gneiss and granite, and consisting largely of pebbles of those rocks.

Another small tract near Pomeroy in Tyrone is important because it exhibits a central ridge of granitoid gneiss flanked by a remarkable group of metamorphosed volcanic rocks which appears to form the local base of the Dalradian series. These rocks consist of coarse agglomerates with interbedded lavas and tuffs, the lavas being chiefly diabases, but including some platy felsitic rocks of more acid type; and this volcanic group is succeeded by green chloritic schists and silvery mica-schists like those of the Scottish Highlands.[7]

It should be remarked that neither in Tyrone nor in any other part of Ireland has anything comparable to the red Torridon sandstones yet been found.

3. *Wales*

In **South Wales** (Pembrokeshire) there is a series of metamorphosed volcanic rocks which underlie beds containing a Lower Cambrian fauna, and are therefore most probably of Pre-Cambrian age. This age was claimed for them by Dr. H. Hicks in 1871, and the results of his examination of the area were described in several

papers.[8] His conclusions may be thus summarised: that the base of the Cambrian system is marked by a conglomerate containing pebbles of the underlying rocks; that this conglomerate rests on a series of schistose volcanic tuffs and breccias, under which is another set of quartz-felsites and halleflintas. Below these again comes a granitoid rock which he regarded as a still older mass of metamorphic rock. To this last he gave the name of *Dimetian*; the overlying volcanic series he called *Pebidian*, but afterwards limited this name to the upper part of the series, proposing the name *Arvonian* for the lower part. (See map, Fig. 13.)

In 1883, however, these conclusions were called in question by Sir A. Geikie, who maintained the correctness of the Geological Survey mapping, holding that the granite is an intrusive mass of igneous rock, and that the volcanic series (Pebidian) is a downward continuation of the Lower Cambrians, the apparent break between them being only a surface of contemporaneous erosion.[9]

Other geologists who have examined the district agree that the granite is intrusive, and that the so-called Arvonian cannot be separated from Pebidian, but are inclined to believe with Dr. Hicks that there is an important volcanic series below the local base of the Cambrian system. On the whole, therefore, it appears probable that there is a series of Pre-Cambrian rocks in Pembrokeshire, that this series should be called the Pebidian, and is several thousand feet thick, but that there is no visible base to it; also that it is pierced by a mass of intrusive granite which may also be of Pre-Cambrian age. The respective interpretations of Dr. Hicks and Sir A. Geikie are shown in Figs. 4 and 5.

In **North Wales** there is again a similar volcanic series making its appearance in two narrow strips or ridges, which rise from beneath conglomerates of Cambrian age. The first extends from Llanllyfin on the south to Bethesda on the north, a distance of about 15 miles, and has a maximum width of 2 miles (see Fig. 14). This tract consists of a rhyolitic felsite succeeded by breccias and schistose rocks.[10]

A second tract extends from Caernarvon to Bangor, a distance of about 10 miles, with a width of over a mile in the central part. This latter has been well described by Professors Bonney and Hughes, who have shown that there are three sets of rocks in the ridge, (1) a granitoid rock at the southern end (Twt Hill), (2) a reddish-purple quartz-felsite, (3) a series of felspathic grits, slates, and agglomerates (the "altered Cambrian" of the Geological Survey). These last are overlain by other conglomerates of Lower Cambrian age. With respect to the relations of these rocks the following facts appear to be well established :—

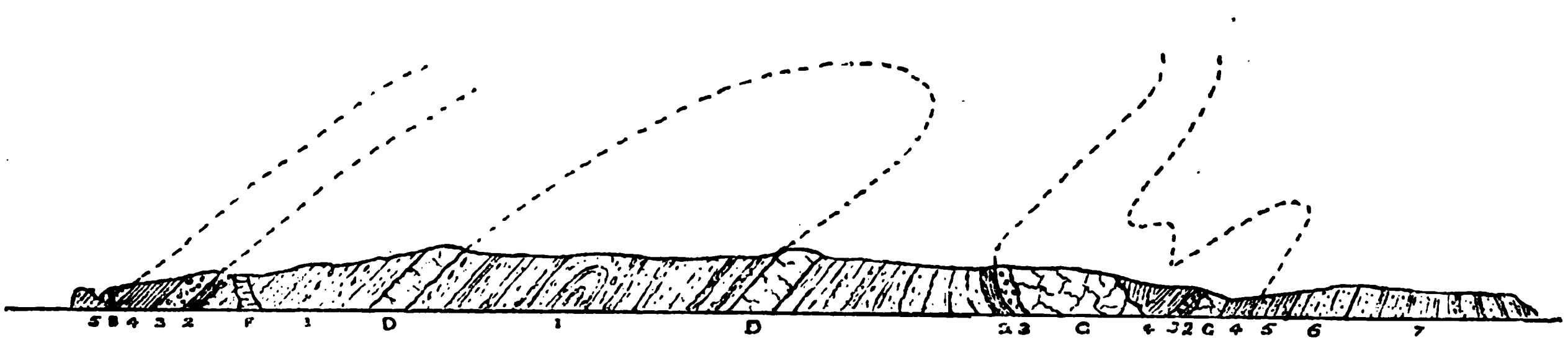

Fig. 4.—SECTION FROM NEAR CASTELL TO PORTH CLAIS, PEMBROKESHIRE (by Sir A. Geikie). Distance about 1¼ mile.

7 and 6. Purple and green grits.
5 and 4. Red and greenish shales.
3. Conglomerate.
2. Porthlisky schists.
1. Volcanic series.
G. Intrusive granite.
D. Diabase lavas.
F. Dyke of quartz-felsite.

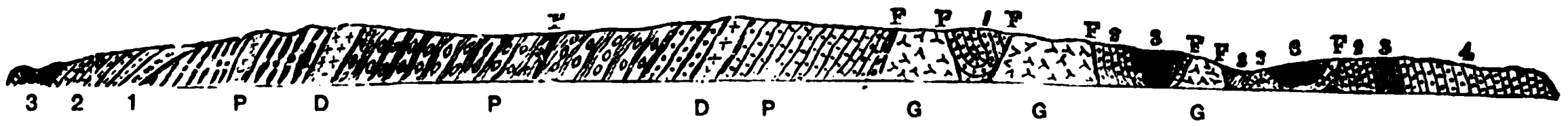

Fig. 5.—SECTION ALONG THE SAME LINE AS FIG. 4 (by the late Dr. Hicks).

3. Shales
2. Sandstones } Cambrian.
1. Conglomerate

P. Pebidian.
G. Dimetian.

D. Diabase lavas.
F. Faults.

(1) That the quartz-felsite was a rhyolite, and probably a rhyolitic lava-flow.
(2) That between this rhyolite and the basal Cambrian conglomerate there is a series of altered volcanic ashes and agglomerates (Bangor series) which are not less than 3000 feet thick.
(3) That the overlying conglomerate contains many fragments of the quartz-felsite and some of granitoid rock (consisting of quartz and felspar) like that of Twt Hill.

It should be mentioned, however, that Sir A. Geikie does not accept the Pre-Cambrian age of this ancient volcanic series. He finds no unconformity at the base of the conglomerate, but regards it as intercalated in the volcanic series, which he consequently considers to be a part of the Cambrian system.

Anglesey.—A large part of this island consists of metamorphic rocks (see Fig. 6), and every one is now agreed that some of them are of Pre-Cambrian age, though opinions differ as to their relative order and succession. Dr. Hicks was the first to describe them as Archæan rocks, and thus writes of the central area near Tycroes: "The granitoid gneiss and more compact granitoid rocks compose the Dimetian axis. Flanking this along the eastern edge are found the breccias and halleflintas of the Arvonian, and beyond . . . these are the micaceous and chloritic schists of the Pebidian."[11] It will be noticed that he compares them with the divisions he had proposed in South Wales, but in his later paper he groups them in two series only, which it is better to call the gneissic series and the schistose series (see Fig. 6).

The latest account of these Anglesey rocks is by Sir Archibald Geikie, who frankly admits that Ramsay's view of their origin was a mistake, and that their delineation on the old map of the Geological Survey is wrong. He recognises that there is in Central Anglesey a core of gneiss which must be regarded as Archæan, and is strikingly similar to portions of the Lewisian gneiss in Sutherland and Ross.[12] As in Sutherland, the gneiss is coarsely foliated and rudely banded and is traversed by frequent veins of pegmatite, consisting of milky quartz with white and pinkish felspar. The schistose series he compares with the Dalradian of Scotland, and describes it as consisting mainly of chloritic schists, green phyllites, with quartzites and schistose grits, and associated but much altered igneous rocks.

Sir A. Geikie remarks that "no one familiar with the Dalradian rocks of Scotland and Ireland can fail to be struck with the close resemblance which these younger Anglesey schists bear

to them, down even to the minutest details. Petrographically

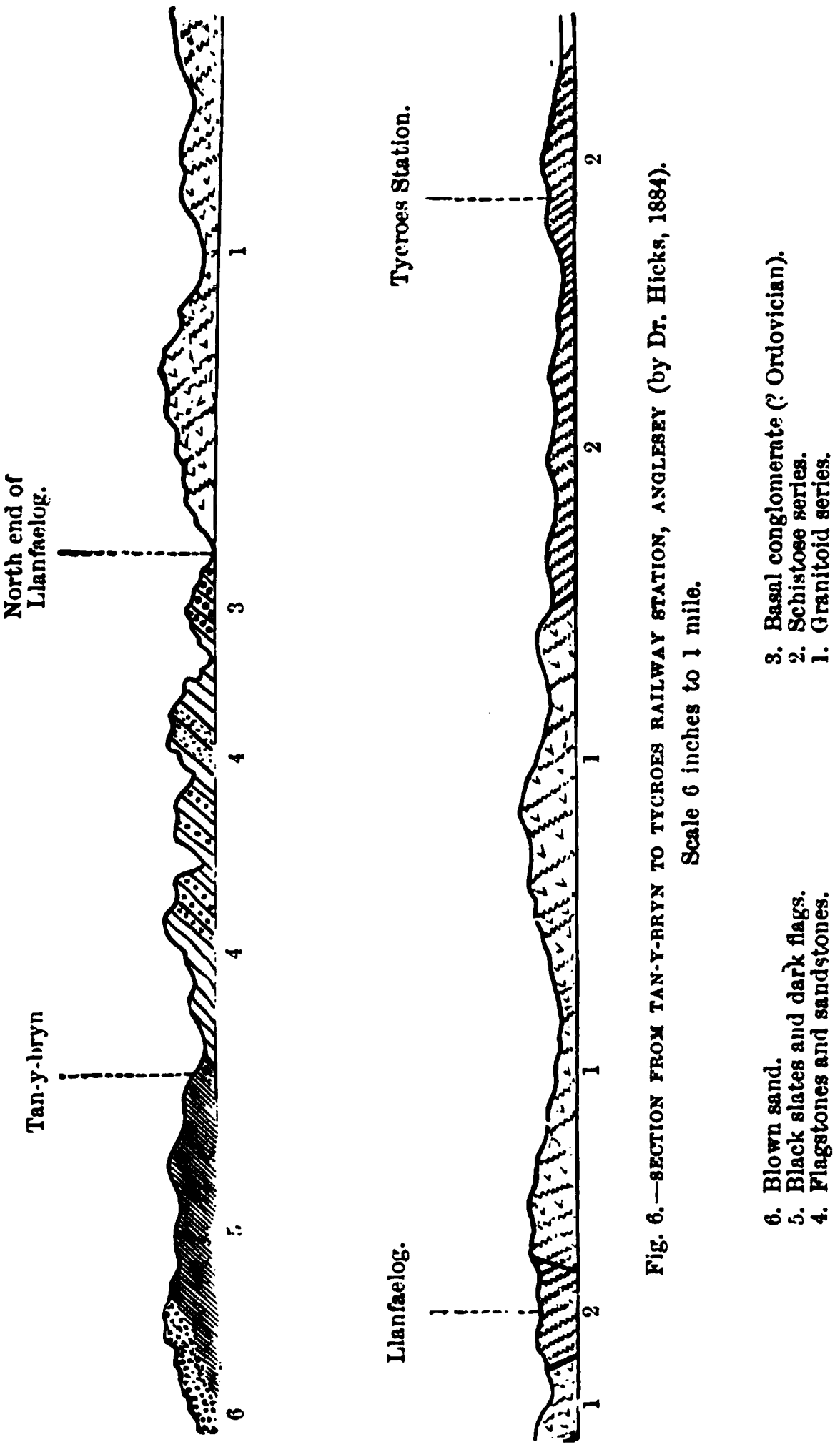

Fig. 6.—SECTION FROM TAN-Y-BRYN TO TYCROES RAILWAY STATION, ANGLESEY (by Dr. Hicks, 1884).
Scale 6 inches to 1 mile.

3. Basal conglomerate (? Ordovician).
2. Schistose series.
1. Granitoid series.

6. Blown sand.
5. Black slates and dark flags.
4. Flagstones and sandstones.

they are the precise counterparts of the quartzites and schists of Perthshire and Donegal, and a farther connection may be established of a palæontological kind"; this is the discovery that

the upper part of the Holyhead quartzite is crowded with annelid pipes.

From what has been said concerning the age of the Dalradian group (p. 49) it will be understood that it still remains to be proved that parts of this complex of schistose rocks in Anglesey are of Pre-Cambrian age.

4. *Shropshire*

In the southern part of Shropshire there are several tracts of ancient rocks which were formerly regarded partly as Cambrian and partly as intrusive igneous rocks (see maps of the Geological Survey and of Sir R. I. Murchison). Broadly speaking, they may be arranged in two great groups or series, the one consisting mainly of volcanic rocks, the other entirely of sedimentary deposits; there is, moreover, a small tract of micaceous schist near Rushton which may be older than either of the others.

The volcanic series is demonstrably Pre-Cambrian, since it is overlain unconformably by rocks containing *Olenellus* and other Lower Cambrian fossils, but this series occurs only in small disconnected patches. The sedimentary series forms the large tract of upland country which is known as the Longmynd (see Professor Lapworth's map (Fig. 7), which is borrowed by permission from the *Proceedings of the Geologist's Association*; this series is almost certainly Pre-Cambrian, but its actual relation to the other group is uncertain because it is bounded on both sides by lines of fault. The prevalent opinion, however, is that the volcanic rocks are older than the Longmynd series, and in accordance with this view the former will be described first.

The volcanic series is known as the *Uriconian*, from the hill called the Wrekin and the Roman town of Uriconium at its foot. The mass of the Wrekin ridge is made up of a succession of rhyolitic lavas with interbedded bands of ash and agglomerate. Midway along the ridge there is an intrusive mass of dolerite, and at each end (*i.e.* on Ercal Hill and Primrose Hill) are patches of granitoid rock which may be intrusive or may belong to an older series. This uncertainty is due to the fact that the junctions appear to be faults.

Rocks similar to those of the Wrekin occur in the Wrockwardine hills to the north-west, as well as in the Caradoc and Cardington Hills near Church Stretton, and this rhyolitic series everywhere strikes nearly east and west, while the Longmyndian and Cambrian rocks strike north-east and south-west (see map). On the western side of the Longmynd, Pontesford Hill is largely made up of

rhyolitic lavas like those of the Wrekin, with intrusive dolerites, and there are other smaller bosses of these rocks on the western side.

The *Longmyndian* or sedimentary series of the Longmynd is divisible into an eastern and western portion. The eastern part appears to be the oldest, and if there is no reduplication of beds the succession is as follows (see Fig. 3), in descending order :—

5. Greenish slates weathering purple, with some grits.
4. Hard greywacke (indurated sandy beds).
3. Purple slates.
2. Banded slates and greywackes.
1. Soft dark shales.

The apparent thickness of these rocks is over 15,000 feet, and they dip regularly to the north-west, the annelid markings and rain-spots on their upper surfaces proving this to be the true dip, and that we follow an upward succession in going from east to west. No definite fossils have been obtained except some impressions, which may be those of a *Lingulella*.

Passing westward this series is succeeded by another set of beds, consisting (1) of purple grits with a thick band of conglomerate in the middle, (2) hard purple slates, and (3) purple and reddish-brown grits with lenticular beds of conglomerate. It is uncertain whether this is a true succession, for it is just possible that the double set of purple grits and conglomerates is a reduplication.

The relation of the western series to the eastern series is also a point of dispute. Professor Blake believes the former to be unconformable to the latter and to be of the same age as some of the grits in the Uriconian group. In his view the eastern or gray series is the oldest rock-group in the district and the Uriconian is newer. In favour of this view it may be remarked that the basal Cambrian sandstones have only been found in contact with the Uriconian and not upon any part of the Longmyndian. On the other hand, numerous fragments of the Uriconian rhyolites occur not only in the conglomerates of the western series, but also occasionally as small fragments in the grits of the eastern series. The evidence of actual unconformity is considered very dubious by Dr. Callaway, who also points out that the strike of the two Longmyndian series is parallel (from north-east to south-west), while that of the Uriconian is quite different (from east to west).[13]

5. *The Malvern Hills*

The oldest rocks of the Malvern Hills are also Pre-Cambrian, and are interesting because the greater part consists of highly

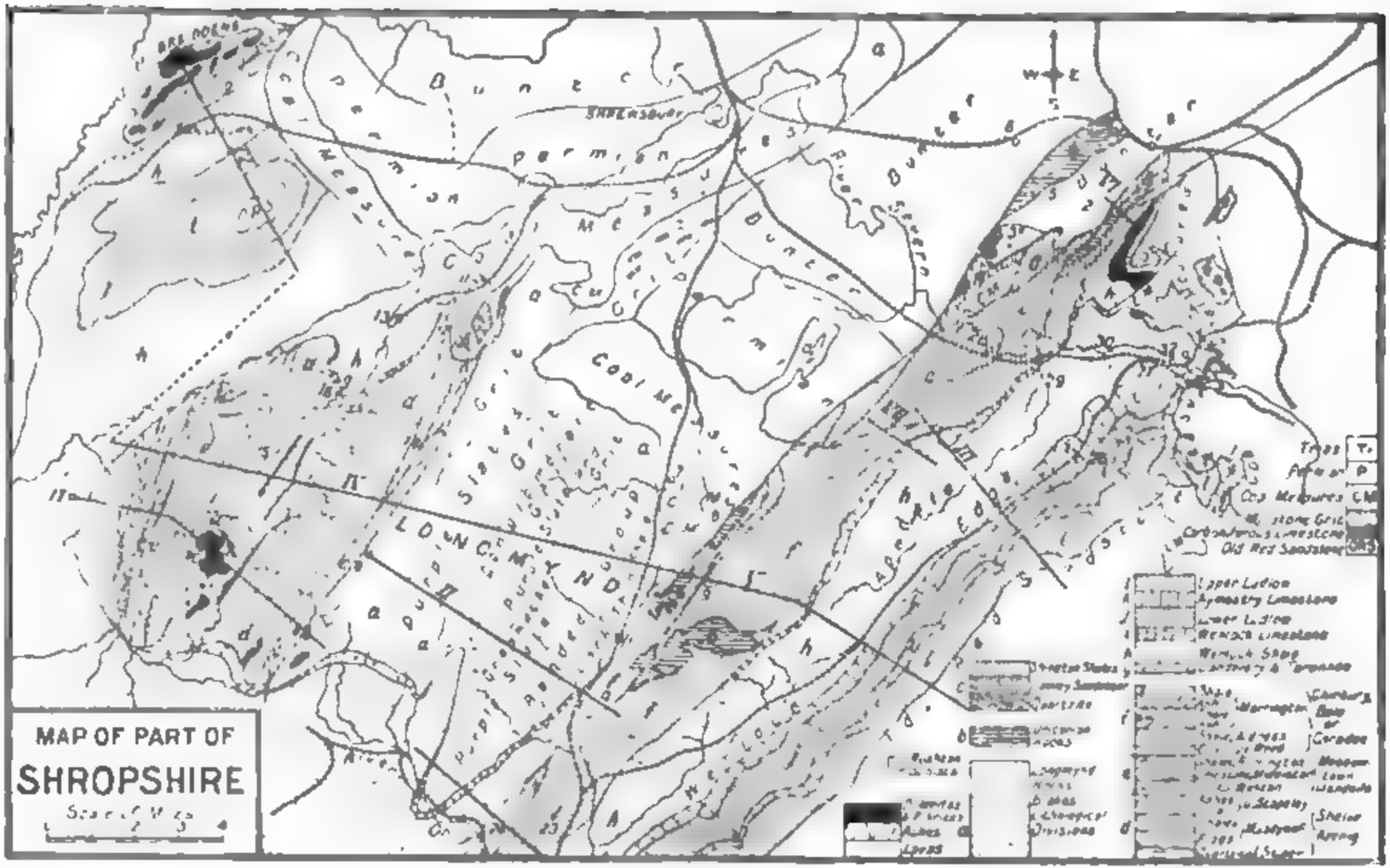
MAP OF PART OF
SHROPSHIRE
Upper Ludlow
Aymestry Limestone
Lower Ludlow
Wenlock Limestone
Wenlock Shale
Old Red Sandstone
Coal Measures
Permian
Bunter
Coal Measures
LONGMYND
Shelve
Arenig

Fig. 7.

crystalline gneissic rocks, which are probably altered igneous rocks, and are comparable to the Lewisian gneisses of Scotland and Ireland. This group is known as the *Malvernian*. Side by side with these is a small tract of rocks comparable with the Uriconian of Shropshire, and consisting of rhyolites, andesites, basalts, and felspathic tuffs.[14] There is nothing here comparable to the Longmyndian series, but the district has undergone an enormous amount of compression with plication, shearing, and faulting, as will be seen from the section, Fig. 8.

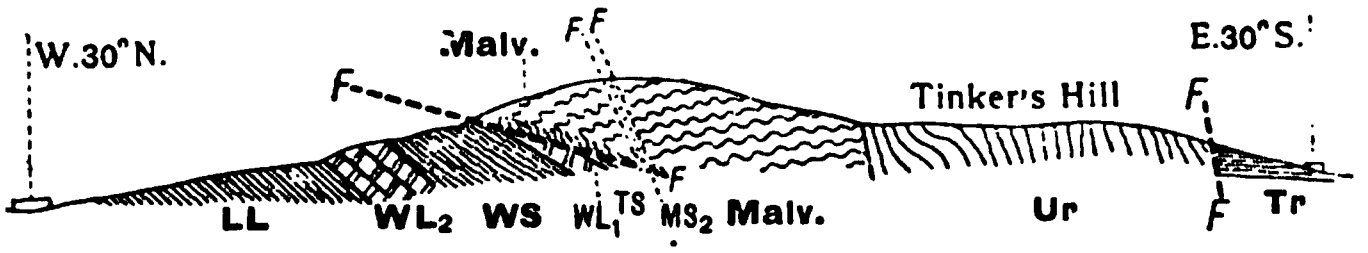

Fig. 8.—SECTION ACROSS THE HEREFORDSHIRE BEACON.
By Professor T. T. Groom (*Quart. Journ. Geol. Soc.* lvi. p. 141).

Tr. = Trias. Malv. = Malvernian. FF. = Faults.
LL to MS_2 = Silurian Rocks. Ur. = Uriconian.

6. *Warwickshire and Leicestershire*

Small tracts of volcanic tuffs and breccias, resembling those of the Uriconian, occur at Barnt Green near Birmingham and at Caldecote near Nuneaton, and are in both cases covered unconformably by Cambrian strata. A larger tract of similar rocks forms the upland district of Charnwood Forest in Leicestershire, and though surrounded on all sides by much newer rocks is probably of Pre-Cambrian age. These Charnwood rocks have been described by Professor Bonney and Rev. E. Hill, who think the following succession can be made out:—

5. Slates of Swithland and Groby.
4. Slates with bands of pebbly quartz grit.
3. Agglomerates and schistose porphyritic rocks.
2. A great series of grits, slates, volcanic ashes, and agglomerates, some of the last being very coarse, and containing large fragments of rhyolitic lava.
1. Slates and fine grits, the latter probably of volcanic origin.

The strike is from north-west to south-east, the older beds occurring on the northern, and the newer on the southern side. Masses of syenite and diorite are intruded among them.

Foreign Pre-Cambrian Rocks

Localities in Europe.—Pre-Cambrian rocks occupy extensive areas in the north of Europe, more than three-fourths of the Scandinavian peninsula consisting of Archæan gneiss, with masses of schist and quartzite, and thin bands of crystalline limestone in the upper part of the series. No definite succession, however, has yet been made out. Rocks believed to be of the same age extend through Finland into Russia.

In Central Europe they appear in several isolated areas surrounded by the stratified rocks of much newer formations. The best known of the areas is that occupying parts of Saxony, Bohemia, and Bavaria between Dresden and the valley of the Danube. The lowest rocks are red gneiss and granite (Bojan gneiss), succeeded by gray gneiss with schistose rocks and beds of limestone and serpentine, and the highest beds consist of mica-schist passing up into clay slate and shales (the Prizbram shales), which are overlaid unconformably by the Lowest Cambrian rocks.

Pre-Cambrian rocks are also known to exist in the Carpathian Mountains and the Pyrenees; gneissic rocks supposed to be of Archæan age occur in Normandy and Brittany, where they present a front of lofty cliffs to the waves of the Atlantic. There can be little doubt that they extend underneath the newer rocks between these districts, and form the floor upon which the latter rest throughout the whole European area.

North America.—The largest and most thoroughly explored area of Pre-Cambrian rocks is that in Canada, forming a broadly V-shaped tract, extending from Labrador to the borders of Lake Huron, and thence north-westward to the Arctic Ocean. These rocks were first described by Sir W. Logan, who called them *Laurentian*, and divided them into two series: (1) a lower group, consisting chiefly of coarse red and gray gneisses and schists with some bands of limestone, and (2) an upper group, found in the neighbourhood of Lake Huron, which he named the *Huronian* series. This rests unconformably upon the Laurentian, and is partly a volcanic and partly a sedimentary series, including lavas, volcanic agglomerates, and tuffs, with green schists, slates, phyllites, quartzites, and bands of limestone. It is now separated into two groups, and its total thickness is estimated at 17,000 feet.

More recently a still higher series has been discovered in Canada. This is called the Keweenawan, and is believed to be unconformable to the Huronian. It consists in the lower part of sandstones and conglomerates with interbedded sheets of basic and

acid lavas, and in the upper part of detrital rocks composed largely of volcanic materials.

Origin and Method of Formation

From the preceding descriptions it will be obvious to the reader that the oldest known rocks are very different from the later sedimentary and volcanic series, and that either the circumstances under which they were formed were different, or that they have been subjected to some special metamorphic processes.

The manner in which these gneissic rocks have been formed has been a subject of speculation and discussion ever since their great antiquity was ascertained. Various explanations have been suggested, and of the theories proposed four may be mentioned as having been strongly held by certain eminent geologists :—

1. That they are the remnants of the first crust that formed on the earth's surface as it cooled down from a state of liquefaction.

2. That they originated, after the formation of the original igneous crust, as chemical sediments in seas of hot water.

3. That they are ordinary sedimentary rocks which have been converted into crystalline rocks by intense subsequent metamorphism.

4. That they are igneous rocks of deep-seated intrusive origin, and that their schistosity is due to subsequent metamorphism, but that their crystalline condition has only been modified and not caused by such metamorphism.

The first of these views was held by Roth and Rosenbusch, and the second was maintained by Sterry Hunt, but both have been abandoned since the foliation of gneiss has been shown conclusively to be a result of dynamic metamorphism. The third view was accepted for many years by most geologists, but its supporters have gradually been driven to admit that if gneiss was originally a sedimentary rock, its alteration has been so great that it must have been reduced in many places to the condition of a semi-molten material not essentially different from that of an igneous rock.

There remains, therefore, the fourth view, which is most in accordance with the ascertained facts and the latest inferences, and consequently this is the view now generally adopted. It does not of itself, however, carry us very far toward realising the actual conditions under which the gneissic rocks were formed. The igneous rocks from which they seem to have been formed, being comparable to such deep-seated plutonic rocks as granite, syenite, diorite, and gabbro, are not likely to have been extruded on to the earth's surface ; they are rocks which, so far as we can judge, must have solidified and crystallised under the pressure of a solid earth-crust. Was

there then such a crust, and if so what was it made of, and how was it possible for the metamorphism of the plutonic rocks to be accomplished in so short a time, *i.e.* before the accumulation of the Torridonian, Uriconian, and Longmyndian series, and before that of the Huronian in America? These are questions which yet remain to be answered.

It is possible that America may furnish more definite answers to these questions than can be obtained in Europe, for wherever the natural surface of the Archæan gneisses can be seen in Europe it is evidently a deeply eroded surface. In the north-west of Scotland it is a surface which has been carved out into hills and valleys, and has all the appearance of having been a land surface for a long period of time, during which a thickness of many hundred feet of rock has been removed from it. In other words, the rocks into which the gneisses were intruded have been removed, but in the Rainy Lake region of Canada the granite gneisses of the Laurentian invade and alter a series of mica-schists and finely laminated gneisses which are regarded by Mr. A. Lawson as metamorphosed sediments.[15] His interpretation of the facts is that the lower Laurentian gneisses were formed "by the fusion of the basement or floor upon which the formations of the upper division of the Archæan were orignally deposited," portions of the latter having been absorbed into the general magma, but that "this fusion only extended up to a certain uneven surface, which surface constitutes the demarcation between the present upper and lower Archæan," which term he uses as equivalent to Laurentian.

However this may be in Canada, there is, near Loch Maree, a remarkable group of mica-schists and quartz-schists, with bands of limestone and seams of graphite, which certainly appear to be altered sedimentaries, and yet are so intimately associated with the Lewisian gneiss that they may be part of the crust into which the gneiss was intruded. Matters are still clearer in Norway, where there is a similar group of altered sedimentary rock, not only associated with Archæan gneiss but actually seen to be pierced by it, and consequently to have been part of the pre-existent crust.

Again, the manner in which our British Lewisian gneiss is veined by pegmatites, and the evidence of successive intrusions of granite, syenite, picrite, and peridotite into the gneissic complex *during the phases of its conversion into a foliated rock* suggest that the period was one of great volcanic activity. It is very probable, though we do not yet know it as a fact, that some of these intrusions reached the surface above, and gave rise to volcanic eruptions with the outpouring of lava streams and the ejection of tuffs and ashes.

From the facts above mentioned we may perhaps venture to infer that the more ancient gneisses were formed when the earth's

crust was comparatively thin, and when it was underlain by a much deeper substratum of liquid matter than subsequently existed, and that as a consequence the crust that had been formed was continually being broken up and crushed by the igneous forces which it temporarily imprisoned, and by the contraction of the earth's mass as it continued to cool. If this is anything like a true conception of the conditions prevailing at this early period of the earth's history, it is obvious that they were likely to develop dynamic energy of much greater power than could be produced in subsequent periods, and this will explain the enormous amount of pressure-force that is evidenced in the shearing, crushing, and deformation of the older gneisses throughout the world.

We have finally to consider the conditions under which the later Pre-Cambrian rocks appear to have been formed. The preceding inferences as to the probable small thickness and instability of the earth's crust and as to the intensity of volcanic action are to some extent confirmed by the phenomena of the later Pre-Cambrian rocks. These undoubtedly furnish us with proofs of very great and extensive volcanic activity, and also of rapid detrition and erosion resulting in the deposition of many thousand feet of stratified materials. Hence it has been inferred that there was a period of some length during which the British area at least formed part of a land surface, and that on this surface numerous volcanic vents were established, from which extensive flows of rhyolitic lava were poured out and great quantities of volcanic detritus were ejected. Then it would seem that portions of the land sank beneath waters in which the products of its detrition by sub-aerial agencies were spread out and accumulated.

Thus Professor Bonney is of opinion that the Pebidian and Uriconian "began with great eruptivity, and that the volcanoes died out contemporaneously with the formation of a thick sedimentary series, the materials of which were in part derived from the dying or dead volcanoes."[16] Again, he writes of the Charnwood district as comparable to the Phlegræan Fields, observing, "The rarity of conglomerates, grits, and rounded detrital materials seems to indicate the absence of either rivers or tidal currents. Such a district then as the Phlegræan Fields, consisting of many low lakes or lagoons, would seem to supply the conditions required for the formation of these Charnwood rocks. The lowness of the hills and the porosity of their materials would be unfavourable to rivers; the ash would settle down in quiet waters, little rolled, or be spread out upon the plain. The land, owing to the frequent showers of ash, might be unfavourable to vegetation, and the volcanic disturbances might render the waters unprolific."[17]

Even in Scotland, where no volcanic rocks of this age have yet been discovered, evidence of their having existed is not wanting, for, as Sir A. Geikie writes, "in some of the conglomerates [of the Torridon sandstone] there occur fragments of highly vesicular lavas, which show that at some time previous to the deposit of these coarse sediments active volcanic vents existed somewhere in the region of the north-west of Scotland." [18]

Finally, portions of the British land surface seem to have sunk so as to allow of the formation of larger water-spaces, which we may call lakes or inland seas, for there is no trace of oceans, and we cannot be sure whether the waters were fresh or saline.

The Torridon sandstone was deposited in one of these basins, and all who have examined that formation have remarked upon its resemblance to a lacustrine rather than to a marine deposit. The Longmynd series was formed in another large water-space, but at present we cannot indicate any shore lines, nor even guess in what directions either of these basins is likely to have been limited.

References

[1] See especially Nicol in *Quart. Journ. Geol. Soc.* vol. xiii. p. 17 and vol. xvii. p. 85, and Murchison in vol. xv. p. 374 (1859).

[2] See especially Callaway in *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 114, and in vol. xxxix. p. 355; also Lapworth on the "Secret of the Highlands" in *Geol. Mag.* Dec. 2, vol. x. pp. 120, 193, and 337.

[3] See *Quart. Journ. Geol. Soc.* vol. xliv. p. 378.

[4] *Annual Report of the Geological Survey for 1893.*

[5] *Quart. Journ. Geol. Soc.* vol. xli. p. 221.

[6] *Proc. Royal Institution for 1889.*

[7] See J. Nolan's *Explan. of Sheet 34 of the Geol. Survey of Ireland* (1878), and Sir A. Geikie, *Address to Geol. Soc.* 1891, p. 42.

[8] See *Quart. Journ. Geol. Soc.* vols. xxxiii. xxxiv. and xxxv.

[9] *Ibid.* vol. xxxix. p. 261 (1883).

[10] See Professor Hughes in *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 137 (1878), and vol. xxxv. p. 682; Dr. Hicks and Professor Bonney in vol. xxxv. pp. 300, 309, 321 (1879), and later papers.

[11] *Quart. Journ. Geol. Soc.* vol. xxxv. p. 302, and vol. xl. p. 193.

[12] *Ibid.* vol. xlvii. Pres. Address, p. 84 (1891).

[13] *Ibid.* vol. xlvii. p. 109 (1891).

[14] Consult Callaway, *Quart. Journ. Geol. Soc.* vol. xxxvi. p. 536 (1880), and vol. li. p. 1 (1895); Rutley, vol. xliii. p. 481 (1887); Acland, vol. liv. 556 (1898); Groom, vol. lv. p. 129 (1899).

[15] See Report on the "Geology of the Rainy Lake Region," *Ann. Rep. Can. Geol. Survey for 1887.*

[16] Letter quoted in the author's *Building of the British Isles*, 1892, p. 29.

[17] *Quart. Journ. Geol. Soc.* vol. xlvii. p. 78.

[18] "Lecture on the Highlands of Scotland and Ireland," *Nature*, vol. xl. p. 300 (1889).

CHAPTER VII

THE CAMBRIAN SYSTEM

Nomenclature of the Lower Palæozoic Rocks.—The establishment of three separate systems among the Lower Palæozoic rocks was not accomplished without much controversy, for in early days only two were recognised, and both were made more comprehensive than they ought to have been.

The well-known name *Silurian* (from the British tribe of *Silures* who inhabited the western parts and borders of Wales) was first introduced by Sir Roderick Murchison in 1835 to designate the series of rocks which he had studied in the land of the Silures (Shropshire, Herefordshire, and South Wales); he divided this system into an upper and a lower series.[1 a]

In the meantime, between the years 1831 and 1835, Professor Sedgwick had worked out the complete succession of the Palæozoic rocks in North Wales, and in 1835 he proposed the name *Cambrian* for this series, which he divided into three portions, calling them Lower, Middle, and Upper Cambrian. For the beds which overlie this series in the Berwyn Mountains he adopted Murchison's name of Silurian.[2]

Sedgwick worked out the succession from below upwards, and Murchison worked from above downwards, and for a long time neither was aware of the fact that their systems overlapped each other. Murchison supposed that Sedgwick's Cambrian lay entirely below his Silurian, but when the fossils were collected and described, it was found that the Upper Cambrian was equivalent to the Lower Silurian, and this fact led to much subsequent controversy.

As Murchison became the Director-General of the Geological Survey, his nomenclature was naturally adopted by the surveyors, and as they found that his Lower Silurian had no natural base, group after group of Sedgwick's Cambrian was gradually absorbed into it, till the Lower Silurian came to include the whole of the

[a] For references see end of the chapter.

rocks (below the Upper Silurian) in which any fossils had been found. This was obviously unfair and unscientific, since the so-called Lower Silurian was in reality a part of Sedgwick's Cambrian series, the delineation of which by Sedgwick was accurate and complete. Still it was done, and the name Lower Silurian was generally adopted both in England and abroad.

The fact is, Sedgwick and Murchison both described more than one system of rocks, and each included two systems under one name. Sedgwick had clearly a right to call one system Cambrian and Murchison to call one Silurian, but there is really a third intermediate system, containing the second great fauna in the life-history of the globe, and to this neither geologist has a distinct claim.

For the intermediate system Professor Lapworth has proposed the name *Ordovician* (from the tribe of the Ordovices who inhabited North Wales), remarking,[3] "That so long as present systems of nomenclature survive, nothing can disturb the application of the title Cambrian to the rocks of the 'Primordial Series,' or that of Silurian to the strata of the 'Third Fauna.' It is vastly different, however, with the intermediate series, which has been the object of incessant disputes from the day it was recognised until now." This proposal has met with very general acceptance, and we may hope, therefore, that it will ultimately be accepted by the Geological Survey.

The following table shows the different arrangements which the student will find current at the present time, the last or right-hand column being that which will be adopted in this volume.

	Sedgwick, 1836.	Murchison, 1839-47.	Geological Survey.	Lapworth, 1879.
Ludlow Beds Wenlock Beds Llandovery Beds	Silurian	Upper Silurian	Upper Silurian	Silurian.
Bala Series Llandeilo Flags Arenig Series	Cambrian	Lower Silurian	Lower Silurian	Ordovician.
Tremadoc Slates Lingula Flags Menevian Harlech Series		Primordial Silurian Cambrian	Cambrian	Cambrian.

Classification of the Cambrian System.—Since the time of Sedgwick and Murchison the Cambrian rocks have been investigated much more completely and fossils have been found at various horizons down to the very base of the system. Fresh subdivisions have been established and new names introduced into the nomenclature. A *Menevian* group has been separated from the Lingula flags, and

the Harlech series was found to be divisible into two groups (the Caerfai and the Solva beds). It has, moreover, been found that the whole succession is divisible into series which are characterised by special genera of trilobites, and that in many places a further subdivision can be made into zones based on the limitation of certain fossils (see p. 25). Thus the old lithological grouping has been modified to agree with the palæontological evidence, and the best modern arrangement of the rock-groups that compose the Cambrian system in England is as follows :—

Upper	Tremadoc Beds	= the *Bryograptus* fauna.
	Lingula Flags (in three stages)	= the *Olenus* fauna.
Middle	Menevian Beds	} the *Paradoxides* fauna.
	Solva Beds	
Lower	= Caerfai Beds	= the *Olenellus* fauna.

Life of the Period.—Great interest attaches to the fossils which have been found in the Cambrian rocks, because, with the exception of the few organic remains mentioned on p. 43, they include the remains of the oldest animals hitherto discovered. At the same time the number of different classes of creatures which exist in the oldest Cambrian fauna make it certain that ancestors of these creatures must have existed in Pre-Cambrian times, and there can be little doubt that some of them will sooner or later be discovered in the higher Pre-Cambrian rocks.

The fossils which have been found in the Lower and Middle Cambrian of Wales and Shropshire are referable to the following classes—Porifera, Cystidea, Annelida, Brachiopoda, Gastropoda, and Crustacea; while representatives of Actinozoa, Crinoidea, Graptolitoida, and Lamellibranchia have also been obtained from rocks of the same age in North America. The very existence of so many different kinds of animals at this early period is a remarkable fact, and is a proof of the great gap which exists between the Cambrian and the Pre-Cambrian rocks of Western Europe.

But although referred to many different classes, examination of the fossils themselves reveals the fact that most of them are represented by lowly and more or less generalised forms—that is, forms which combine in themselves characters that are now only found in two or more distinct families or orders of beings. Thus sponges (Porifera) may be regarded as intermediate between Protozoa and Cœlenterata; and the Cambrian Actinozoa (*Archæocyathus*) are such simple forms that they were long regarded as Porifera.

The Cystidea again are placed by systematists at the bottom of the Echinoderma and appear to represent an early stage in the evolution of the Echinoderm race.

Two of the Lower Cambrian Brachiopods (*Lingulella* and *Orbiculoidea*) are low forms of that class, and the others, *Obolella* and *Kutorgina*, were not much more highly organised. No Lamellibranchia have yet been found in the Lower Cambrian of Europe, but some small fossils found in North America are referred to this class. The Gastropoda are represented by the genus *Hyolithes* and its allies, which are usually referred to the Pteropods, a group that retain to the present day many embryonic characters. More typical Gastropods appear in the Lower Cambrian of America and in the Middle Cambrian of Scotland.

Of Crustacea two orders are represented, the Entomostraca and Trilobita. The former are true Crustacea of low organisation; the latter exhibit a curious mingling of characters, which have led some authors to exclude them from the Crustacea, but Professor Beecher [4] remarks that Trilobites show the clearest evidence of primitive Crustacean affinities. He also observes that the Trilobite agrees in nearly every particular with a theoretical Crustacean ancestor, and we may add that it may also have been the ancestor of the Merostomata and the Arachnida.

In the Middle and Upper Cambrian Hydrozoa (Graptolites), Crinoid and Asteroid Echinoderms, Phyllocarid Crustacea, other genera of Pelecypoda and Gastropoda, and Nautiloid Cephalopoda make their appearance. The occurrence of Cephalopoda, the highest of the Molluscan classes, suggests that the evolution and development of marine Mollusca must have been especially rapid during this early period of the earth's history, or else that their ancestors existed somewhere long before Cambrian times.

The following are the principal characteristic species of the several faunas which have been recognised in the Cambrian system.

Lower Cambrian (*Olenellus Fauna*)

Porifera.	Protospongia fenestrata.
Annelida.	Serpulites fistula, Scolithus linearis.
Trilobita.	Olenellus Callavei, O. Lapworthi, O. intermedius, Olenelloides armatus.
Brachiopoda.	Lingulella primæva, Orbiculoidea cäerfaiensis, Kutorgina cingulata, Obolella Salteri.
Gastropoda.	Hyolithes princeps, Orthotheca Geeri, Stenotheca rugosa, Coleoloides typicalis, Salterella pulchella, S. Maccullochi.

Middle Cambrian (*Paradoxides Fauna*)

Porifera.	Protospongia fenestrata, P. major.
Cystidea.	Protocystis menevensis.
Trilobita.	Paradoxides Harknessi, P. solvensis, P. aurora, P. Davidis, and P. Hicksi, Conocoryphe coronata, C. viola, C. Lyelli, and C. solvensis, Plutonia Sedgwicki, Agnostus cambrensis, Microdiscus sculptus.

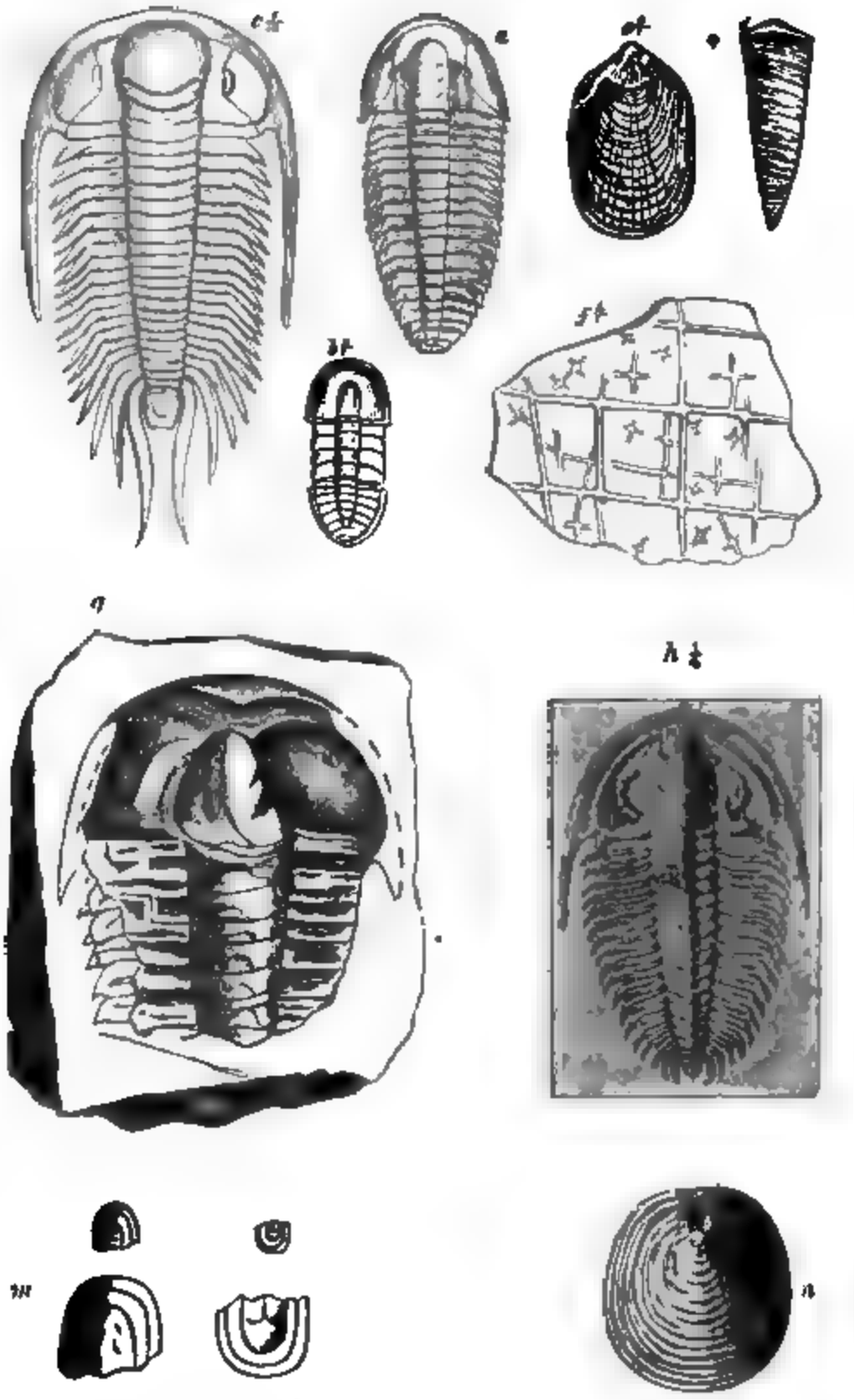

Fig. 9.—GROUP OF LOWER CAMBRIAN FOSSILS.

a. Conocoryphe Lyelli.
b. Microdiscus sculptus.
c. Paradoxides Davidis.
d. Hyolithes corrugatus.
e. Lingulella ferruginea.
f. Protospongia fenestella.
g. Paradoxides aurora.
h. Olenellus Callavei.
m. Agnostus Cambrensis (nat. size and enlarged).
n. Orbiculoides pilcolus (much enlarged).

Brachiopoda. Lingulella ferruginea, Obolella sagittalis, Orbiculoides pileolus, Orthis Hicksi.

Gastropoda. Hyolithes antiqua, H. penultima, Cyrtotheca hamula, Stenotheca cornucopia.

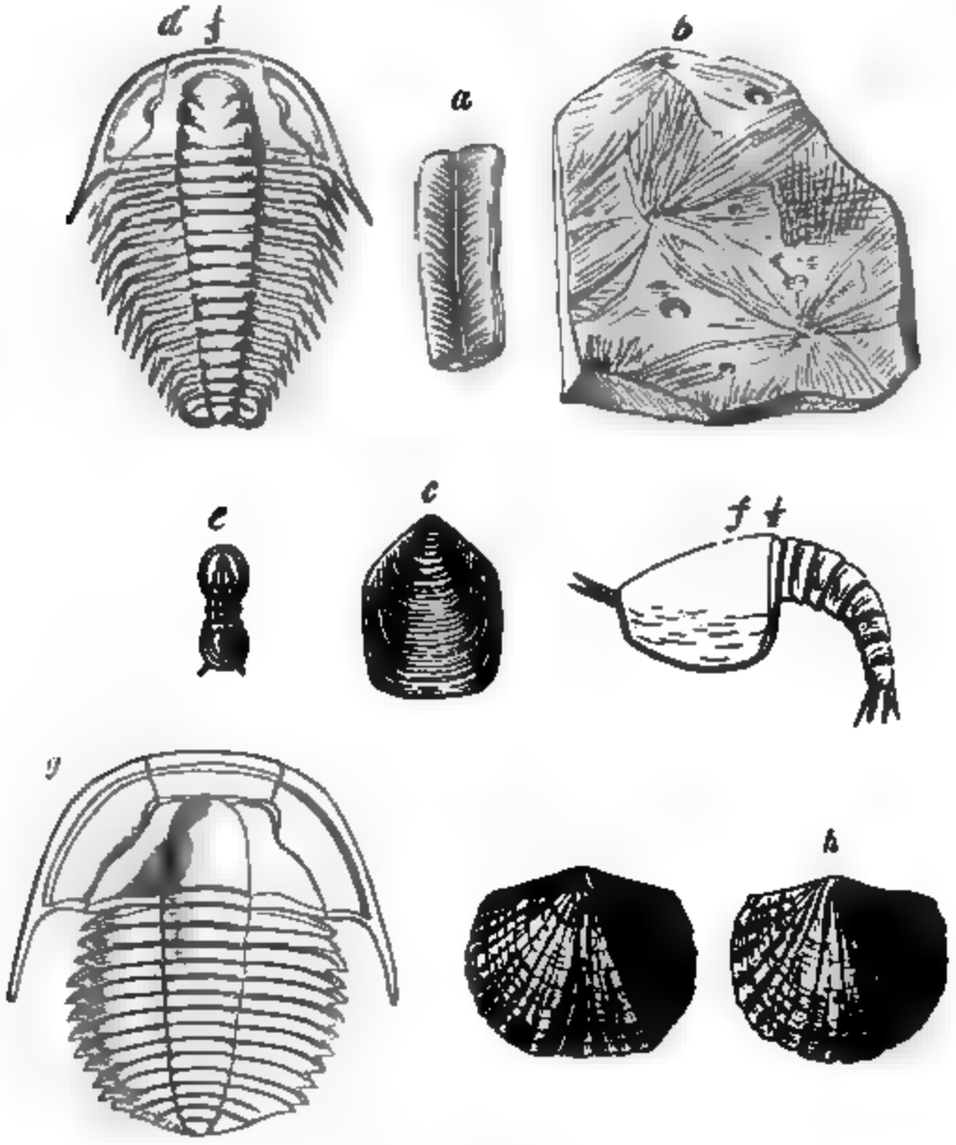

Fig. 10.—GROUP OF LINGULA FLAG FOSSILS.

a. Cruziana semiplicata.
b. Dictyonema sociale.
c. Linguiella Davisi.
d. Olenus micrurus.
e. Agnostus pisiformis.
f. Hymenocaris vermicauda.
g. Conocoryphe bucephala.
h. Orthis lenticularis.

Upper Cambrian (Olenus Fauna)

Hydrozoa. Dictyonema sociale (highest Lingula flags).

Annelida. Cruziana semiplicata.

Trilobita. Olenus truncatus, O. micrurus, Peltura scarabæoides, Parabolina spinulosa, Conocoryphe bucephala, Solenopleura depressa, Agnostus pisiformis, A. trisectus.

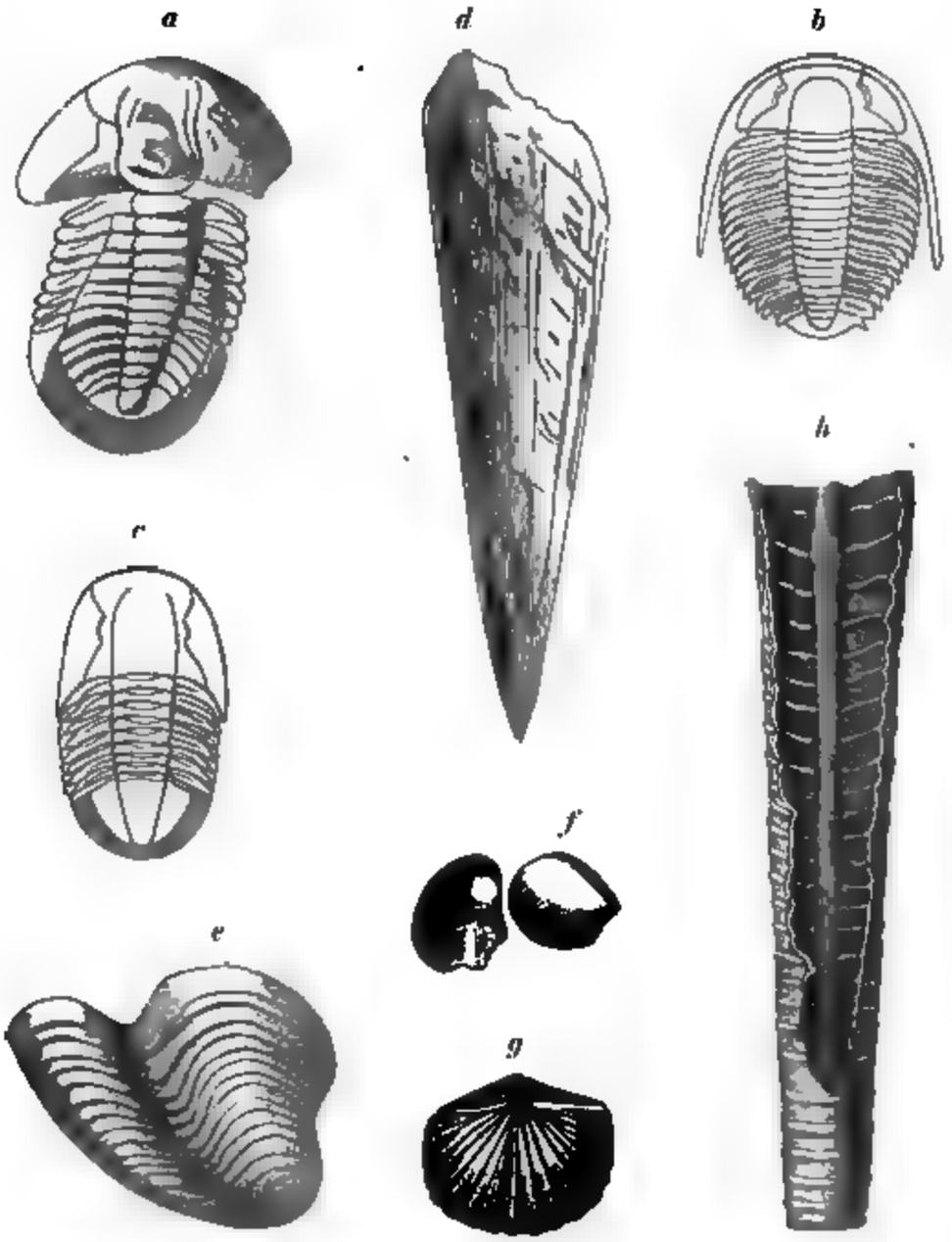

Fig. 11.—GROUP OF TREMADOC FOSSILS.

a. Asaphus Homfrayi.
b. Angelina Sedgwicki.
c. Niobe Homfrayi.
d. Conularia Homfrayi.
e. Bellerophon arfonensis.
f. Palæarca Hopkinsoni.
g. Orthis Carausi.
h. Orthoceras mendax.

Phyllocarida. Hymenocaris vermicauda.
Brachiopoda. Lingulella Davisii, Orthis lenticularis (pass to Tremadoc).
Gastropoda. Bellerophon cambrensis, Hyolithes (Theca) corrugata, H. obtusa.

The Passage Fauna (Tremadoc)[1]

Porifera. Archæoscyphia minganensis, Calathium sp.
Hydrozoa. Bryograptus Callavei, Br. Kjerulfi, Clonograptus tenellus.
Echinoderma. Dendrocrinus (? Iocrinus) cambrensis, Palæasterina ramseyensis, Macrocystella Mariæ.
Trilobita. Niobe Homfrayi, Psilocephalus innotatus, Asaphus affinis, A. Homfrayi, Angelina Sedgwicki, Ogygia scutatrix, Olenus alatus, Peltura punctata.
Brachiopoda. Lingulella lepis, L. Davisii, Obolella Belti, Orthis lenticularis, and O. Carausi, Orthisina festinata, O. striatula.
Lamellibranchia. Palæarca Hopkinsoni, Glyptarca primæva, Ctenodonta menapiensis, Modiolopsis ramseyensis, Euchasma Blumenbachiæ.
Gastropoda. Hyolithes cuspidatus, Conularia Homfrayi, Bellerophon arfonensis, Ophileta complanata, Maclurea Peachi, Eunema pagoda, Murchisonia gracilis.
Cephalopoda. Orthoceras sericeum, O. mendax, O. durinum, Piloceras invaginatum, Cyrtoceras precox.

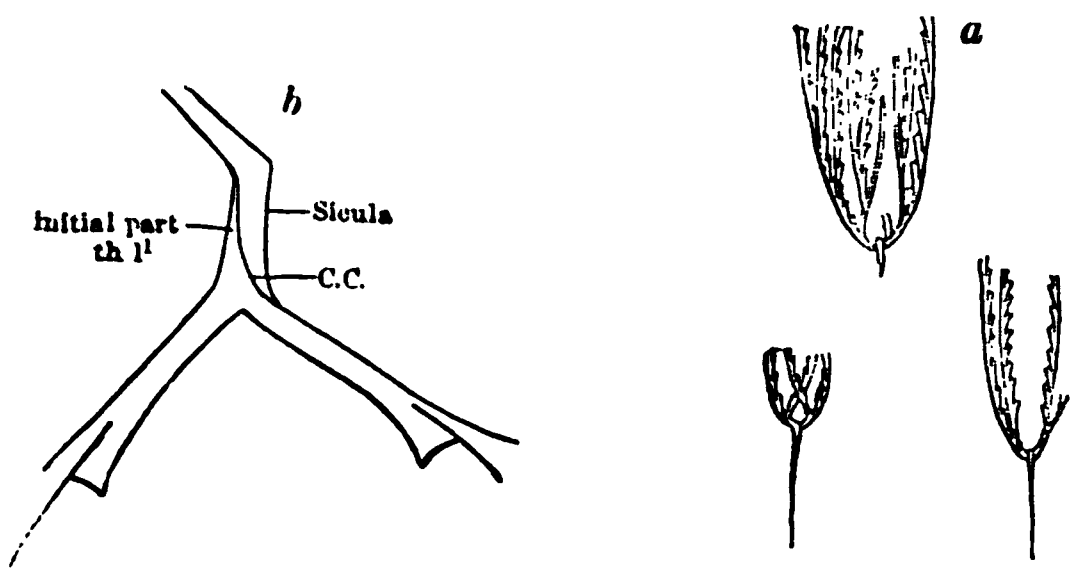

Fig. 12.—A TREMADOC GRAPTOLITE, BRYOGRAPTUS KJERULFI (from the figure by Miss Elles).

a. Specimens of natural size. *b*. A part magnified.

STRATIGRAPHY

Cambrian rocks rise to the surface in several parts of the British Isles, but they nowhere occupy any large tract of country, so that we can only compare their isolated exposures, and cannot trace their stratigraphical variations continuously from one district to another.

In England and Wales there are six districts where the occurrence of Cambrian strata is unquestionable; these are (1) South Wales, (2) North Wales, (3) Shropshire, (4) The Malvern Hills, (5) Warwickshire, (6) Lake District. In Scotland they have only yet been found in the north-western area (Sutherland Ross, and Inverness), but may also be represented in the complex

[1] The upper limestones of Durness are included in this group.

of the Central Highlands. In Ireland there are tracts of rock in Wicklow and Wexford which are usually regarded as Cambrian, but the few fossils they have hitherto yielded are not of a nature to make this certain.

Wherever the basement beds of this system are exposed they are seen to rest unconformably upon an irregular surface of the Pre-Cambrian rocks.

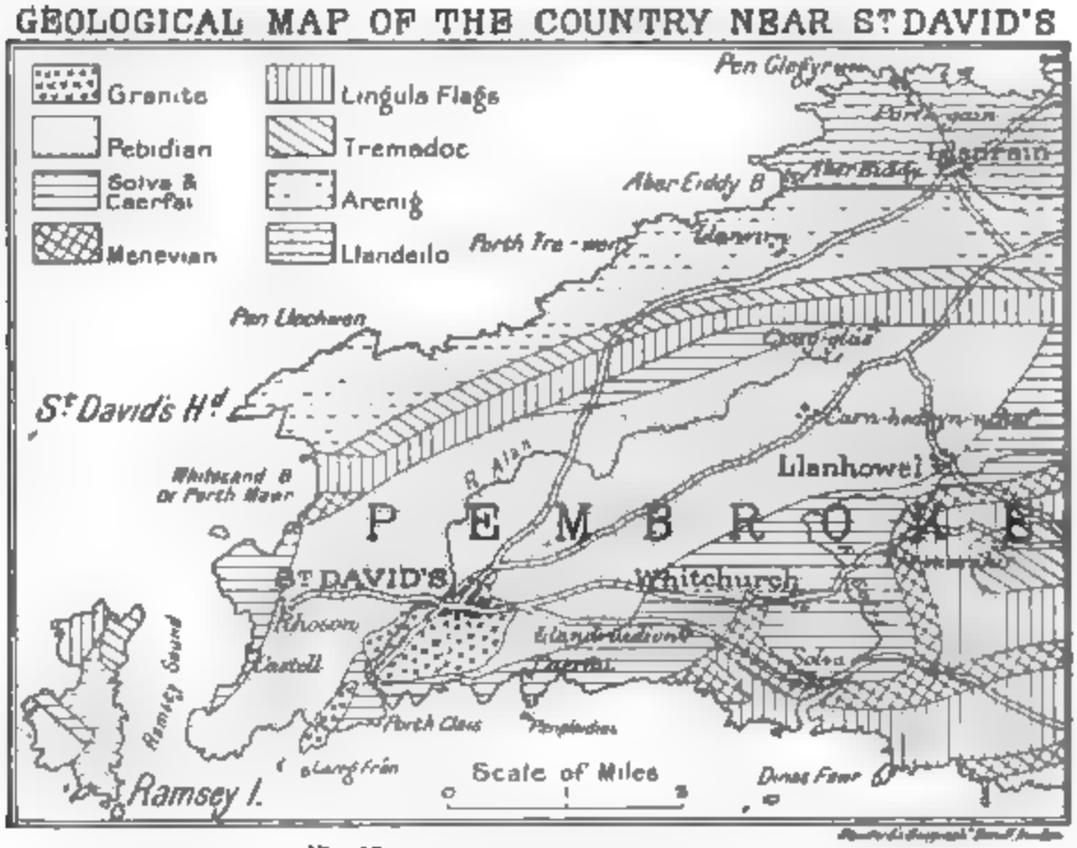

Fig. 13.—MAP OF PART OF SOUTH WALES.

1. *South Wales*

On the maps of the Geological Survey the area which is coloured and labelled as Cambrian in South Wales includes that which has since been described as Pebidian (Pre-Cambrian), while the Upper Cambrians (Lingula flags and Tremadoc slates) are excluded and regarded as part of the Lower Silurian or Ordovician system (see p. 65). Thus the usefulness of the Survey map is greatly diminished, and Dr. Hicks's map, published in 1884, is a better guide. Fig. 13 is reduced from this.

The whole Cambrian succession is well exposed in the St. David's promontory (Pembrokeshire), and has been described in several papers by the late Dr. Hicks,[5] of which the following is

CORRELATION TABLE OF BRITISH CAMBRIAN ROCKS

	South Wales.	North Wales.	Malvern and Shropshire.	Warwickshire.	Lake District.	N. Scotland.
Upper.	Upper Tremadoc, Lower Tremadoc, ? 1200 feet.	Upper Tremadoc, Lower Tremadoc, 1000-2000 feet.	Shineton shales, Malvern gray shale, 1500 feet.	Merevale shales.	Lower Skiddaw slates.	Upper Durness limestone, ? 700 feet.
	Lingula Flags { Upper, Middle, Lower, 2000 feet.	Dolgelly Beds, Ffestiniog Beds, Maentwrog Beds, 5000 feet.	Black shales of Malvern, 800.	Oldbury shales, 1000 feet.		Middle and Lower Durness limestones, ? 800 feet.
			Wanting.	?		
Middle.	Menevian Beds, 750 feet.	Menevian Beds, 230 feet.	Wanting.	Purley shales, 600 feet.		
	Solva Series { Upper, Middle, Lower, 1800 feet.	Coarse grits, slates with Conocoryphe viola, ? 2000 feet.				
Lower.	Caerfai Series, with Olenellus, 1600 feet.	Grits, slates, and conglomerates, 2000-3000 feet.	Hollybush and Comley sandstones and quartzitic conglomerate up to 1000 feet.	Hartshill quartzite, 600 feet.		Serpulite grit and quartzites, 600 feet.

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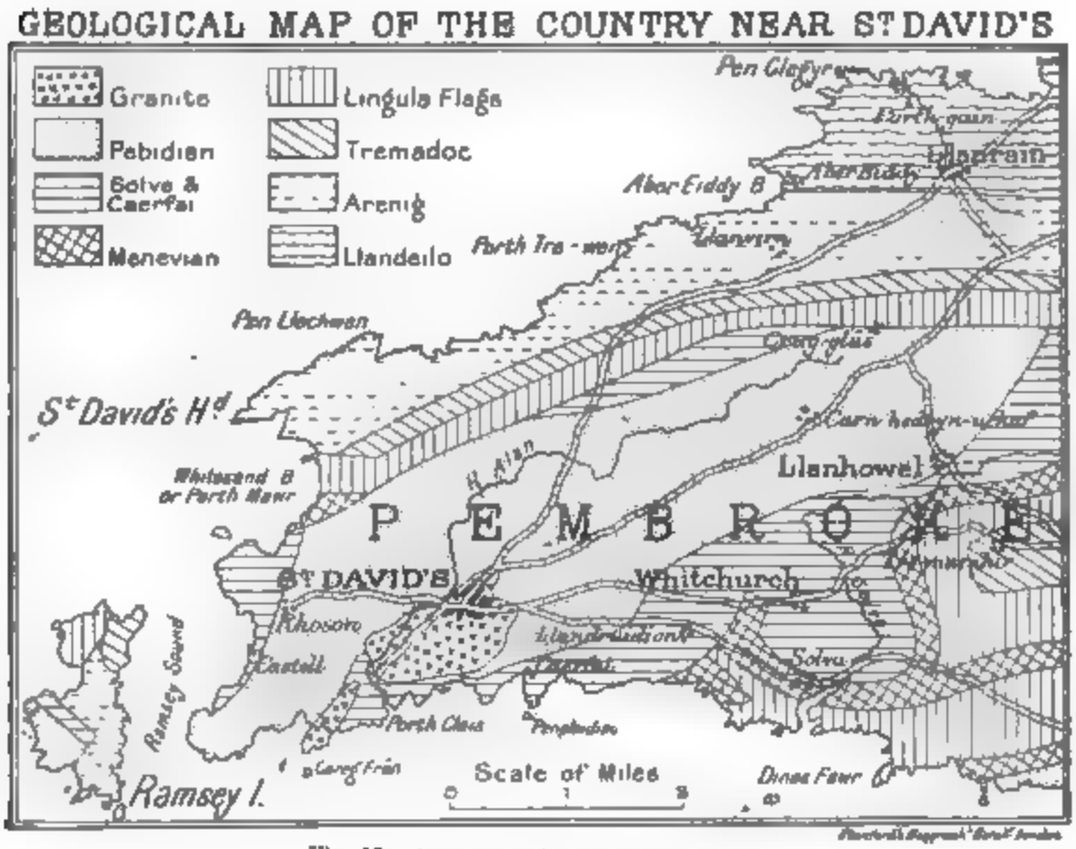

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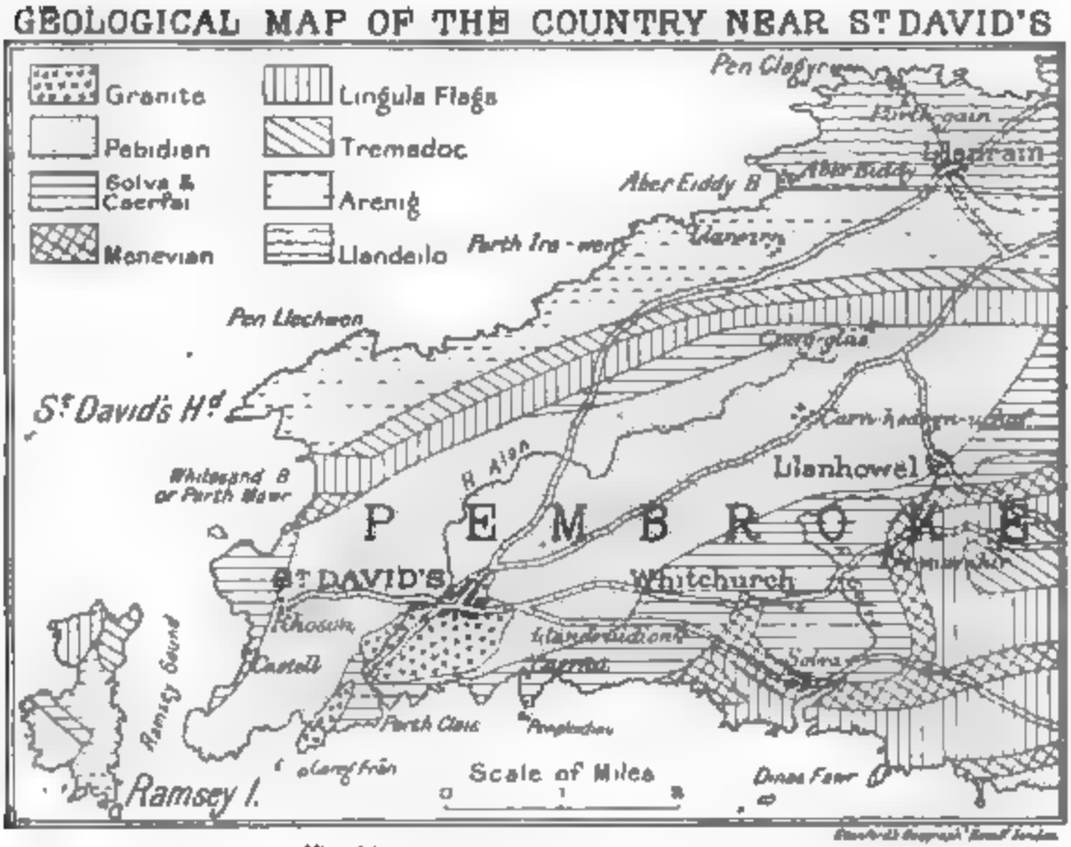

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Lower.	Caerfai Series, with Olenellus, 1600 feet.	Grits, slates, and conglomerates, 2000-3000 feet.	Hollybush and Comley sandstones and quartzitic conglomerate up to 1000 feet.	Hartshill quartzite, 600 feet.		Serpulite grit and quartzites, 600 feet.

a summary. The total thickness is over 7000 feet, and the system is divisible into the following groups :—

Caerfai Series.—This is described as composed of the following beds in descending order :—

	Feet.
Purple sandstones with Annelid tracks	1000
Red shales with *Lingulella primæva, Discina*, and fragments of *Olenellus*	50
Flaggy sandstones with Annelid markings	460
Conglomerates	60 to 150
	About 1600

The basal bed of this series is the Cambrian conglomerate so frequently mentioned in the preceding chapter. Near St. Davids it is about sixty feet thick, and consists of well-rounded pebbles set in a matrix which is a mixture of arkose and ashy materials; sometimes the ashy element appears to predominate, sometimes it is a true arkose, consisting of quartz-sand and decomposed felspar. The pebbles vary in size, ranging up to a foot in diameter; they consist principally of a reddish quartzite and of quartz, but include some of quartz-felsite, porcellanite, schist, and granitoid rock, all derived from the underlying Pre-Cambrian rocks.

Solva Series.—This is divisible into the following stages :—

	Feet.
Gray flagstones and grits with *Paradoxides aurora* . . .	150
Red, purple, and gray sandstones and slates with *Paradoxides solvensis*	1500
Yellowish sandstones and gray flags with *Paradoxides Harknessi* .	150
	1800

The lowest beds are yellowish sandstones with some pebble beds, and above these are gray flags which have yielded a number of fossils, including *Paradoxides Harknessi, Plutonia Sedgwicki, Microdiscus sculptus, Conocoryphe Lyelli, Agnostus cambrensis*, and *Hyolithes antiqua*. The central group is of great thickness and yields fragments of fossils at different horizons, but it was only near the top that Dr. Hicks found *Paradoxides solvensis* and *Conocoryphe solvensis* with some other fossils. The upper beds contain other species of *Paradoxides* and *Conocoryphe*, while *Agnostus cambrensis* and *Lingulella ferruginea* occur in all three groups.

Menevian Series.—The Solva beds pass gradually into a series of dark flags and shales, which contain a remarkable fauna; above these sandstones again appear, marking, possibly, an upheaval of the area, and certainly indicating some physical change, for with them the species and genera characteristic of the Lower

Cambrian die out and disappear. The group is thus subdivided by Dr. Hicks :—

	Feet.
Upper—Sandstones and shales, with *Orthis Hicksii* . . .	100
Middle—Flags and shales, with *Paradoxides Davidis* . . .	350
Lower—Flags and shales, with *Paradoxides Hicksii* . . .	300
	750

The middle group yielded to Dr. Hicks no fewer than twenty-eight species of fossils belonging to the following genera: *Protospongia*, *Protocystis*, *Microdiscus*, *Conocoryphe*, *Paradoxides*, *Anopolenus*, *Erinnys*, *Arionellus*, *Holocephalina*, *Agnostus*, *Lingulella*, *Discina*, *Obolella*, *Orthis*, *Hyolithes*, *Stenotheca*, and *Cyrtotheca*.

Lingula Flag Series.—In South Wales this does not seem to be more than 2000 feet thick, and fossils are not very abundant in them, but they are well exposed in Whitesand Bay and in the cliffs of Ramsey Island (see Fig. 13), and they have been divided by Dr. Hicks into three groups, which probably correspond with those recognised in North Wales by Mr. Belt. These are in descending order as follows :—

	Feet.
Upper—Fine gray slates without fossils	300
Middle—Hard gray micaceous flags with *Lingulella Davisi* in abundance	1000
Lower—Gray flagstones and black slates without fossils . . .	700

These beds appear to form a continuous band along the northern side of the Cambrian area from Whitesand Bay to and beyond Crygglas; east of St. Davids they are seen in Solva Harbour, and inland they spread eastward round another tract of Lower and Middle Cambrian rocks of which little is yet known. Near the eastern end of this tract, at Trefgarn, north of Haverfordwest, a small but interesting exposure was found by Messrs. Marr and Roberts in a quarry which showed shales with *Parabolina spinulosa*, underlain by a few feet of grit and conglomerate, which rested unconformably on a surface of nearly vertical Pre-Cambrian rocks. Unless the position of these beds can be explained by faulting it would seem as if the Upper Lingula flags had here overlapped the lower beds and were resting directly on Pre-Cambrian rocks.

Tremadoc Series.—This group of rocks was mapped near St. Davids by the late Dr. Hicks, who separated it from the Lingula flags on the one side and from the overlying Arenig slates on the other, and showed that it occupied a tract of country extending from Whitesand Bay to Llanvirn, south of Abereiddy Bay, and occurred also in Ramsey Island (see map, Fig. 13).

He restricted the name, however, to a group of dark flaggy sandstones and earthy slates about 1000 feet thick in which he discovered a remarkable fauna, including *Neseuretus ramseyensis*, *Niobe Homfrayi*, *Dendrocrinus cambrensis*, and species of *Ctenodonta*, *Palæarca*, and *Modiolopsis*. Above these beds are some dark iron-stained slates which Dr. Hicks regarded as Lower Arenig because he found dendroid graptolites (*Cladophora*) in them, but he admitted that they were the equivalents of the Upper Tremadoc slates of North Wales. The fossils found at this horizon in Whitesand Bay included *Asaphus Homfrayi*, *Ogygia scutatrix*, *Lingulella Davisi*, *Dendrograptus arbuscula*, and *Callograptus radiatus*. It is very probable that both Upper Tremadoc and Lower Arenig beds exist at this locality, but they have not yet been separated, and consequently the thickness of each is unknown.

Another small tract of Lower Tremadoc beds is found round Tremanhire, a place about four miles east of St. Davids ; they are brought in above the Lingula flags by a synclinal flexure, and have yielded many of the same fossils as in Ramsey Island.

Tremadoc slates have also recently been found to the south of Caermarthen by the Misses Crosfield and Skeat,[6] and their presence there is important, as it had not previously been suspected. They yielded *Orthoceras sericeum* and two new trilobites named *Peltura punctata* and *Ogygia marginata*.

The fact is that the whole of the Cambrian and Ordovician areas in South and Central Wales will have to be mapped over again before any reliable statements can be made regarding the exposures of the Tremadoc and Lower Arenig rocks and regarding their relations to one another. The maps of the Geological Survey published in 1845 and 1848 were excellent for that time, but the region is so complicated, folded, and faulted that even with larger-scale maps and a better knowledge of fossils it will be a difficult and laborious matter to unravel its structure and to separate the various rock-groups which enter into the complex.

2. *North Wales*

Cambrian rocks occur in Merioneth and Caernarvon, and are brought to the surface from beneath the surrounding Ordovician strata by two great anticlinal folds which are separated by the great synclinal of the Snowdon range (see Fig. 14). The eastern uplift, which is really a dome-shaped pericline, is that of the Harlech and Barmouth district. The western axis is of considerable length, running from Nevin north-eastward to Aber, and may be called the Llanberis anticline.

GEOLOGICAL MAP OF A PART OF NORTH WALES

Fig. 14.—MAP OF NORTH WALES.

In North Wales the equivalents of the Caerfai beds (Lower Cambrian) have not yet been clearly separated from the succeeding beds (Solva group), and the two together are consequently still known as the Harlech series, for although this series appears to be thicker than the combined Caerfai and Solva series of South

Wales, few fossils have yet been obtained from it in spite of much careful search, and without such aid subdivision is difficult.

• **The Harlech beds** of Merioneth have been described by Sir A. Ramsay as consisting mainly of coarse quartzose greenish-gray grits, composed of quartz and felspar, and apparently formed from the direct waste of granitic rocks. There are occasional beds of conglomerate, consisting of quartz pebbles, with some of felspathic rock, enclosed in a gritty matrix. With these coarse gray grits are some beds of finer grain and purple colour, and occasional bands of gray and purple slate. In the centre of the tract there is some thickness of purple slate which Ramsay regarded as the lowest part of the series, the base not being seen. Dr. Hicks, however, was inclined to regard these lowest slates as possibly Pre-Cambrian, and thought the base of the Cambrian and the equivalent of his Caerfai beds could be found in Llawlech Mountain north of Barmouth.

According to Ramsay the total thickness of the Harlech series in the central area is over 6000 feet, but in the northern part the same beds are only 4200 feet thick (without a base).

In Caernarvon the basal beds are grits and conglomerates, which contain pebbles of granite, quartz-felsite, and porcellanite derived from the Pre-Cambrian rocks described in the preceding chapter. These are succeeded by a thick series of purple and green slates, some of which are worked at the celebrated slate quarries of Penrhyn and Llanberis; above these again are coarse grits and sandstones. The total thickness on the eastern side of the anticline near Llanberis is estimated at about 3000 feet.

A *Conocoryphe* (*C. viola*) was obtained from the upper green slates of the Penrhyn quarry in 1887, and the succession in that vicinity was described in 1889 by Professor Hughes, from whose paper the following account is taken (in condensed form):—

		Feet.
	Lingula flags with *L. Davisii*.	
10.	Coarse grits and sandstones of Bronllwyd	? 600
9.	Green slates with *Conocoryphe viola*	120
8.	Purple slates without fossils	970
7.	Bluish-green slates with some traces of fossils	? 400
6.	Fine red grit	15
5.	Purple and veined slates	540
4.	Green sandy slates	? 400
3.	Grit and conglomerate	? 300
2.	Crumpled slates	
1.	St. Ann's grit	

Of these beds Nos. 1 to 6 may represent the Caerfai group and Nos. 7 to 10 the Solva group. On the north-western side of the

Llanberis anticline some of the Llanberis grits and slates come in again and plunge beneath a narrow strip of Arenig slates. They are brought up again by the Bangor anticline, but in that district there does not seem to be anything to represent the Harlech series; there are slates which may be Lingula flags, and below these are grits and conglomerates which rest unconformably on the older rocks (see Figs. 14 and 15).

Menevian Series.—These beds have been identified at many points along the cincture of the Harlech and Barmouth pericline, and there is no doubt that they form a narrow band all round it between the Harlech series and the Lingula flags. Their thickness however, is believed to be less than in South Wales. Near Ffestiniog, in the northern part of the area, their thickness is estimated by Ramsay as 225 feet, but it is probable that they are thicker in the south, though their exact limits have not yet been made out. They are well exposed at Dolgelly, at Pont-ar-Camlan on the river Mawddach, and on the coast half a mile east of Barmouth. They consist of dark blue and black slates, and have yielded both the characteristic species of *Paradoxides* with *Anopolenus Henrici*, *Conocoryphe Homfrayi*, *Erinnys venulosa*, and some other fossils.

Whether any representative of the Menevian exists near Llanberis or elsewhere in Caernarvon is not yet known.

Lingula Flags.—This series attains a great thickness in Merioneth. The beds are well exposed at Dolgelly and Ffestiniog, and are classified as follows by Mr. Belt:—

		Feet.
Upper or Dolgelly	Soft black slates, with *Peltura scarabæoides*	300
	Hard blue slates, with *Parabolina spinulosa*	300
Middle or Ffestiniog	Bluish gray flags, with *Olenus micrurus*	50
	Gray micaceous flags, with *Hymenocaris vermicauda*	2000
Lower or Maentwrog	Black slates and flags, with *Olenus gibbosus*	1800
	Sandstones and slaty beds, with *Olenus cataractes*	700
		5150

In Caernarvonshire the thickness of the Lingula flags is much less, but near Llanberis and Nant Ffrancon they are apparently from 2000 to 2500 feet thick. On each side of Llyn Peris the nearly vertical Harlech grits are succeeded by dark slates which represent the Maentwrog beds, with a thickness of about 1000 feet, and these are followed at the eastern end of the lake by hard quartzose grits (? Ffestiniog beds), which are estimated by Ramsay to be about 1300 feet thick.[7] These beds are traceable northward through Elidyr-fawr, and a good section is exposed in the southern cliffs of Marchlyn-mawr (see Fig. 17), where Ramsay

Fig. 15.—DIAGRAM SECTION ACROSS CAERNARVONSHIRE (by Professor T. M. Hughes). Distance 11 miles.

d. Bala and Llandeilo beds.
c. Arenig series, with pisolitic ironstone (*p*) at base.
b. Lingula flags.
a^2. Llanberis slates.
a. Cambrian grits.
F. Faults.
D. Dykes of igneous rock.
x. Broken ground.

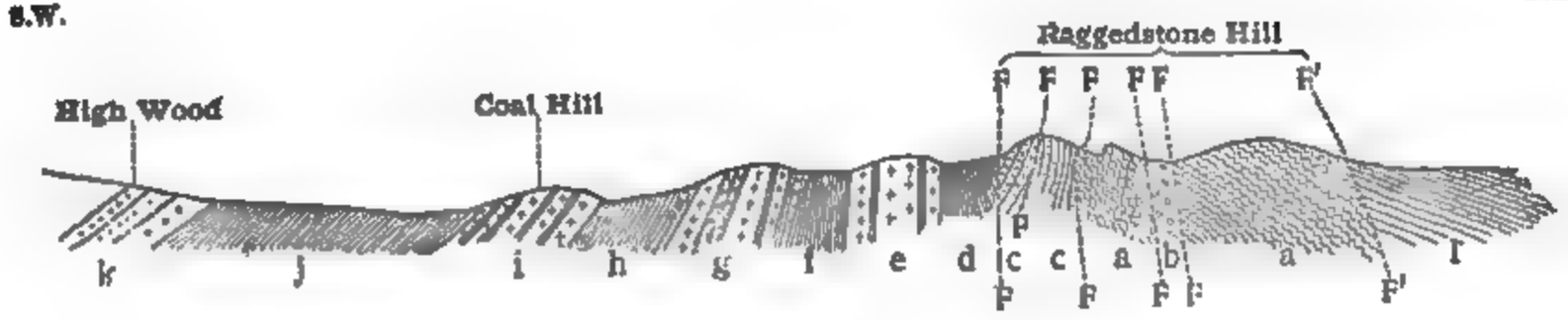

Fig. 16.—SECTION ACROSS THE CAMBRIAN TRACT OF THE MALVERN HILLS (by Professor T. Groom). Distance about one mile.

j, h. Gray shales.
i, g, a. Sills of igneous rock.
f, d. Black shales.
c, b. Hollybush sandstone.
} Cambrian rocks.

l. Trias.
k. Llandovery beds.
d. Pre-Cambrian gneiss.
FF. Faults.

found *Olenus micrurus* and *Lingulella Davisii* in the gray and brown grits (No. 5). It is noticeable that some of these grits are of coarse grain, and occasionally conglomeratic, thus differing from the finer-grained flagstones of Merioneth. The Upper Lingula flags or Dolgelly beds have not yet been identified in Caernarvon owing to the rarity of fossils, but are probably represented by a part of the slates above.

On the western side of the Llanberis anticline the thickness of the Cambrian series seems to be still further reduced, and when they again emerge on the eastern flank of the Bangor-Caernarvon ridge there are only slates overlying the basal grits and conglomerates.

Professor Hughes[8] has traced these basal beds along the eastern flank of the Pre-Cambrian ridge all the way from Twt Hill near Caernarvon to Garth Point near Bangor. The pebbles vary

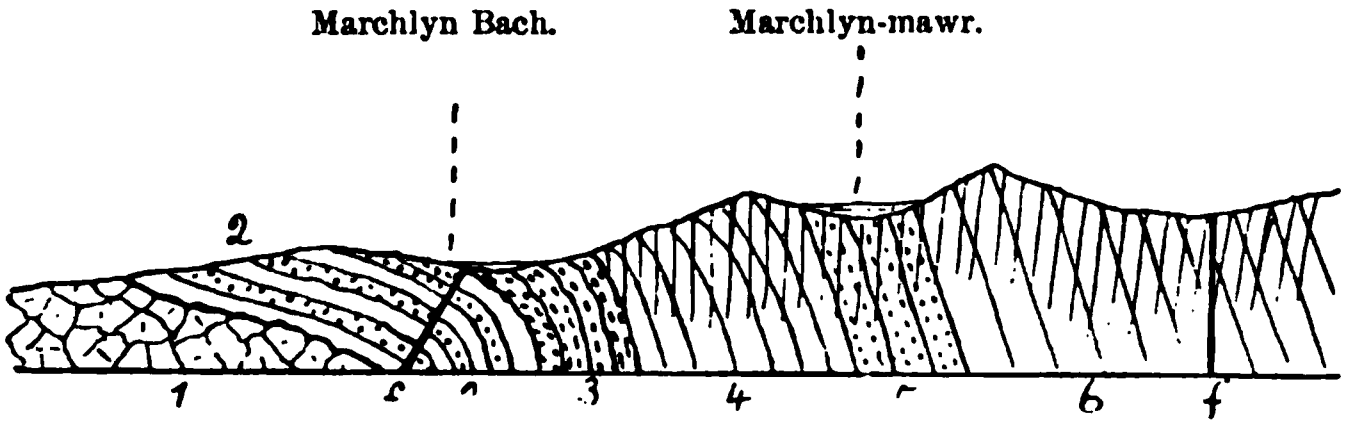

Fig. 17.—SECTION THROUGH MARCHLYN-MAWR (Ramsay).

6. Arenig and ? Tremadoc.
5. Grits } Lingula flags.
4. Slates }
3. Grits } Harlech beds.
2. Slates and grits }
1. Quartz porphyry (Pre-Cambrian).

according to the rocks on which the conglomerate locally rests; near Caernarvon they are chiefly quartz, near Llanddeiniolen they are all of felsite, and near Bangor there are pebbles of quartzite, felsite, and quartz.

Sir A. Ramsay was of opinion that the whole of the Lingula flags had thinned out near Bangor, that the grits were of Harlech age and were overlain unconformably by Arenig shales. This, however, is not the generally accepted view, for there is no evidence of such unconformity, and if the diminution of thickness is due to thinning out toward a shore line we should expect the lower beds to thin out and disappear before the upper beds. The facts may be explained as a simple case of overlap, and we may suppose that the whole of the Harlech series (*i.e.* Lower and Middle Cambrian) has thinned out with probably some of the Lingula slates (Maentwrog beds) and that the basal Cambrians between Llanddeiniolen and Bangor represent the Lingula grits of Elidyr-fawr and Marchlyn-mawr. They may, however, be of still later date.

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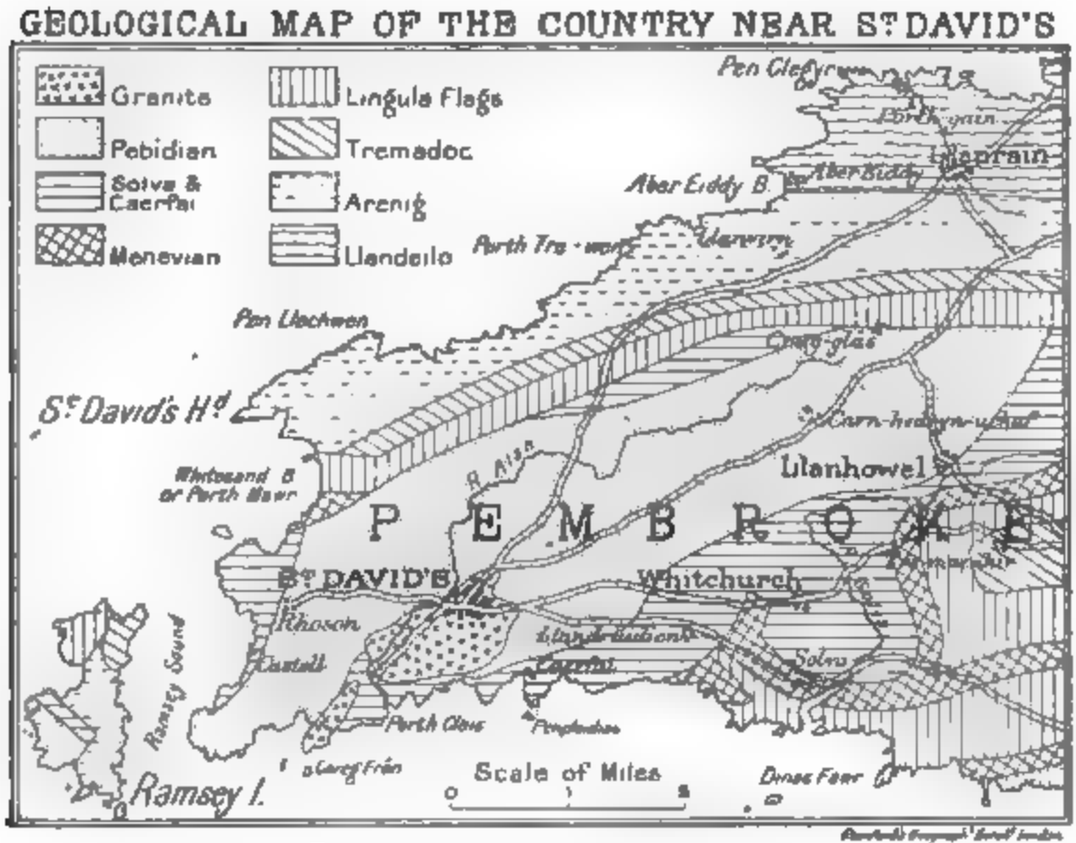

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	Lingula Flags { Upper, Middle, Lower, 2000 feet.	Dolgelly Beds, Ffestiniog Beds, Maentwrog Beds, 5000 feet.	Black shales of Malvern, 800.	Oldbury shales, 1000 feet.		Middle and Lower Durness limestones, ? 800 feet.
			Wanting.	?		
Middle.	Menevian Beds, 750 feet.	Menevian Beds, 230 feet.	Wanting.	Purley shales, 600 feet.		
	Solva Series { Upper, Middle, Lower, 1800 feet.	Coarse grits, slates with Conocoryphe viola, ? 2000 feet.				
Lower.	Caerfai Series, with Olenellus, 1600 feet.	Grits, slates, and conglomerates, 2000-3000 feet.	Hollybush and Comley sandstones and quartzitic conglomerate up to 1000 feet.	Hartshill quartzite, 600 feet.		Serpulite grit and quartzites, 600 feet.

In the Wrekin area the succession is similar. There the lowest bed is a hard quartzite, with pebbles of rhyolite and other rocks in the lower part. This is succeeded by greenish sandstones like those of Hollybush, including a reddish sandy limestone, which near Comley has yielded *Olenellus Callavei*, *Kutorgina cingulata*, *Stenotheca*, and some other fossils. The upper beds consist of conglomerates, grits, and shales, with another band of limestone in which *Ptychoparia*, *Obolella*, and fragments of *Paradoxides* have been found. Hence these *Comley sandstones* appear to represent both the Caerfai and Solva beds of South Wales.

In the Lickey district there is an exposure of quartzite which is almost certainly of Lower Cambrian age, though no fossils except worm-burrows have yet been found in it. It consists of flaggy quartzites, with intercalated purple shales like those next described.

Near Nuneaton there is a remarkable tract of Cambrian rocks

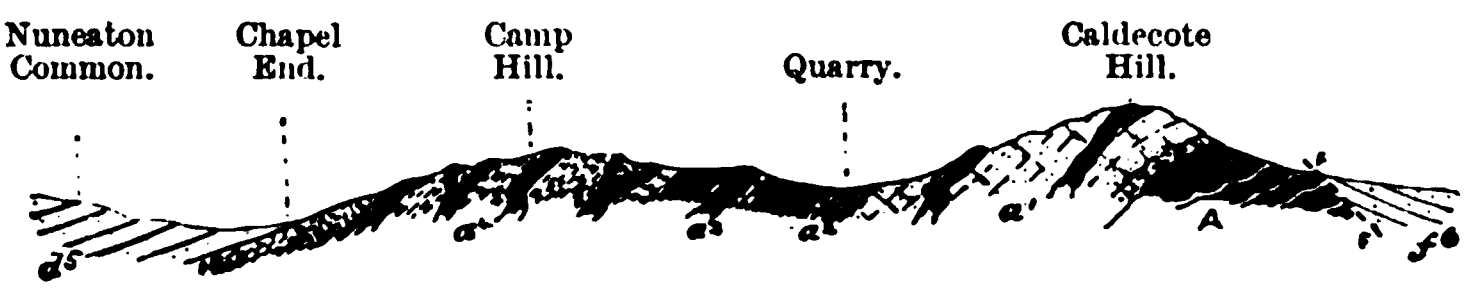


Fig. 19.—SECTION FROM NUNEATON TO CALDECOTE HILL (Lapworth).

f^6. Keuper marls.
d^5. Coal-measures.
a^4. Oldbury shales.
a^3. Purley shales.
a^2. Hyolithes beds.
a^1. Cambrian quartzite.
A. Caldecote volcanic rocks.
Diorite dykes shown in black.

which before the discovery of fossils was supposed to be of Carboniferous age. It is about 9 miles in length, with a width of a mile where broadest, and the structure of the district is shown in the section drawn by Professor Lapworth (Fig. 19). The arenaceous division has been called the Hartshill quartzite, and is about 600 feet thick. It has been divided into three parts by Professor Lapworth. The Lower or Park Hill quartzite is composed of alternating beds of siliceous grit and purple or gray shale, the grits consisting of sand set in a chalcedonic cement, and forming a very hard rock which has usually a pale pink colour. No fossils have yet been found in them. The Middle or Tuttle Hill quartzite consists of thick beds of quartzitic grit with very little shale, and has not yielded any fossils. The Upper or Camp Hill quartzite is a much more varied set of beds, consisting at the base of thin-bedded glauconitic grits, followed by sandy micaceous shales about 50 feet thick, in which are two notable beds, one a pebble bed or conglomerate, and the other a bed of red limestone about 2 feet thick. Above the shaly beds is a mass of purple false-bedded

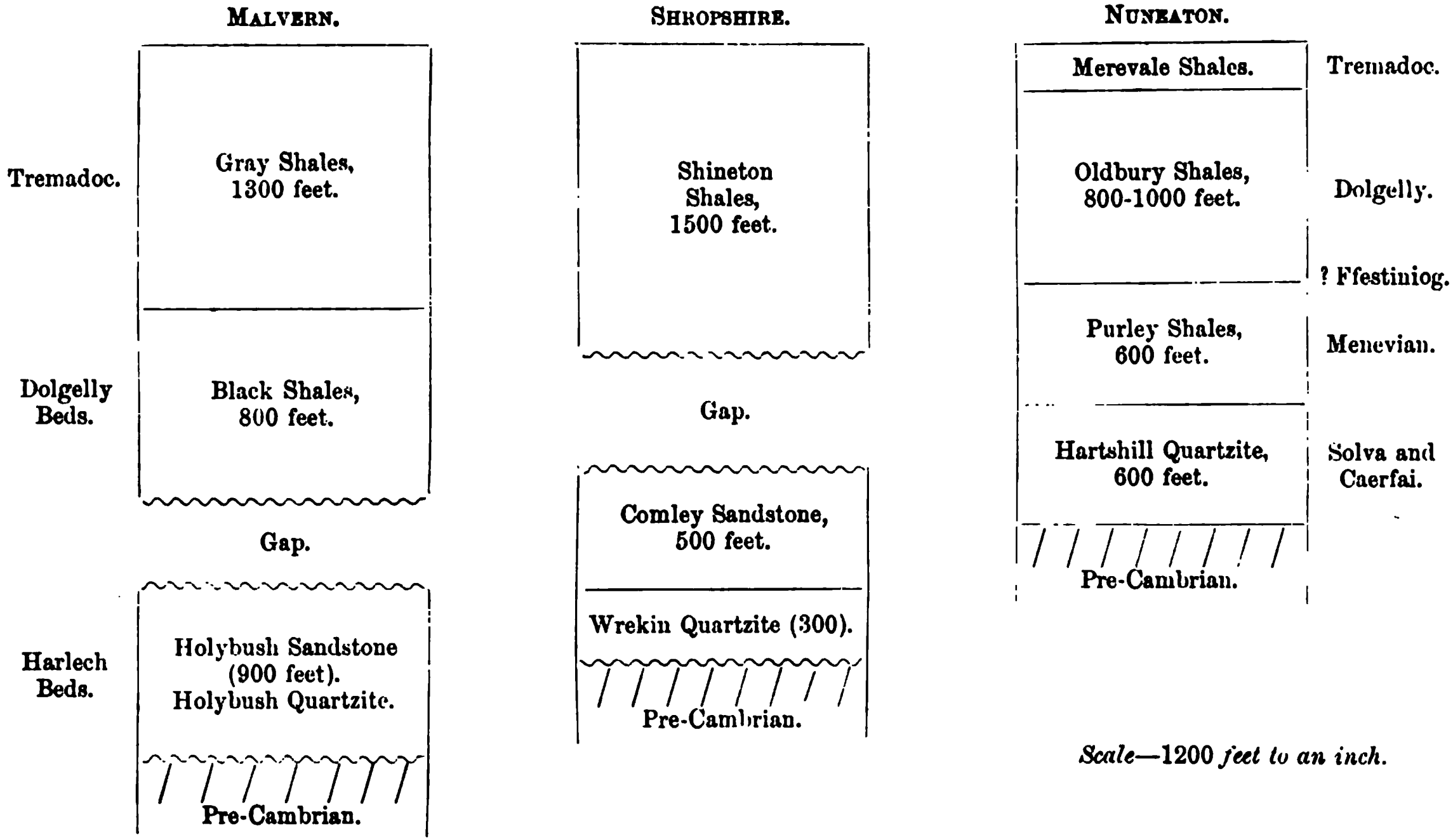
quartzitic sandstone containing many grains of glauconite and about 50 feet thick.

The limestone and associated red shales have yielded several species of *Hyolithes* and of *Orthotheca*, with *Stenotheca rugosa*, *Coleoloides typicalis*, *Kutorgina cingulata* and *Iphidea labradorica*, and *Orthisina transversa*. The facies of the fauna is that of the Lower Cambrian or *Olenellus* zone, though no trilobites have yet been found.

The Shaly Division (Upper Cambrian).—In the Malvern area this is over 2000 feet thick, and is divisible into two parts. The lower, 800 feet, are black shales with bands of basaltic lava which have generally been regarded as contemporaneous lava-flows, but which Professor Groom finds to be intrusive sills. These shales have yielded *Olenus (Peltura) scarabæoides*, *Ctenopyge bisulcata*, *Agnostus trisectus*, *Sphærophthalmus alatus*, etc.—species which are characteristic of the Lower Dolgelly beds of North Wales. Several genera of Foraminifera have also been found by Professor Groom in these shales, and identified by Mr. F. Chapman. The upper part of the Malvern shales is composed of bluish or yellowish gray shales, with many intrusive sills of basalt and diabase. Professor Groom[11] finds them to be of much greater thickness than was previously supposed, and from his section, reproduced in Fig. 16, it will be seen that they are at least 1300 feet thick. Their highest beds contain *Dictyonema sociale*, *Agnostus dux*, *Cheirurus Frederici*, *Acrotreta Sabrinæ*, with species of *Asaphus* and *Olenus*; most probably they are of Lower Tremadoc age. No representatives of the Menevian, Maentwrog, or Ffestiniog beds have yet been recognised, but Professor Groom is of opinion that the boundary between the Hollybush sandstone and the Malvern shales is everywhere a faulted one, so that beds of intermediate age may be faulted out.

In Shropshire the *Shineton shales* occupy a tract two miles broad in the valley of the Severn by Shineton and Cressage, and they extend both to the north-east and south-west (see map, Fig. 7). They also occur at Pedwardine, and again in a long narrow strip on the west side of the Longmynd, where they underlie the Arenig beds of the Stiper Stones. Their true age was first made known by Dr. Ch. Callaway,[12] who discovered in them fossils of Upper Cambrian types. He describes them as soft, fissile, micaceous shales of a dark blue colour, weathering to olive-green and yellow. Their base is not seen, and their junction with the Comley sandstone appears to be a fault, so that here, as at Malvern, the central part of the Cambrian system seems to be missing. The lowest beds contain *Dictyonema*. The highest beds are more fossiliferous and have yielded many trilobites, including *Eulonia*

TABULAR CORRELATION OF THE MIDLAND CAMBRIANS



Scale—1200 *feet to an inch.*

monile, *Olenus Salteri*, *Asaphellus Homfrayi*, *A. Crofti*, *Conophrys salopiensis*, and *Lichapyge cuspidata*, with the Cystidean *Macrocystella Mariæ*. The total thickness is estimated at about 1500 feet and the beds are clearly of Tremadoc age.

Passing again to Nuneaton, where the Hartshill quartzite is succeeded by the Stockingford shales, we have what appears to be a complete succession without break or faulting. Professor Lapworth has divided the shaly series into three groups, of which the following is a brief description, taking them in descending order :—

Upper or Merevale Shales.—Only seen near Merevale, and consisting of greenish-gray shales in which *Dictyonema* is abundant. The thickness exposed may be 200 feet.

Middle or Oldbury Shales.—Black shales, with some bands of gray shale ; in highest beds are *Sphærophthalmus alatus* and *Ctenopyge pecten ;* in the lower *Agnostus pisiformis*, *Olenus Salteri*, *Beyrichia Angelini*, and a *Lingulella*. Thickness probably 800 feet.

Lower or Purley Shales.—Reddish-purple mudstones and shales, with some green and gray bands, containing minute *Lingulella*, *Obolella sagittalis*, *Acrothele granulata*, and a *Conocoryphe*. Thickness about 600 feet.

The fauna of the Purley shales is comparable with that of the *Conocoryphe exulans* zone of Sweden, which belongs to the *Paradoxides* division and is homotaxial with our Menevian series. The black Oldbury shales are comparable with the black shales of Malvern and the Lower Dolgelly beds. The Merevale shales appear to represent the lowest part of the Shineton shales and of the Malvern gray shale. No horizon comparable with the mass of Lingula flags has been recognised, but this may be due to the scarcity of fossils in the lower part of the Oldbury shales.

A tabular correlation of the Midland Cambrian beds is given on page 86.

4. *Lake District*

In the northern part of the Lake District around Skiddaw Mountain, Derwent, and Crummock Waters there is a great thickness of dark-coloured slates, with bands of hard grit and occasional beds of conglomerate. To these beds Sedgwick gave the name of Skiddaw slates ; the higher portion of them is of Ordovician (Arenig) age, but the lower part is Cambrian (Tremadoc and Lingula flags). The Cambrian age of this portion was suspected by Sedgwick and maintained by Clifton Ward, but not till 1894 was this view confirmed by good palæontological evidence.[13]

Mr. Ward took a certain band of grit occurring north of Skiddaw as the base of the Arenig series and identified with it certain flaggy grits near Buttermere. This view may be generally correct ; but it

seems to make all the western part of the district to consist of Cambrian rocks, yet there are localities within this western area which have yielded Arenig graptolites.

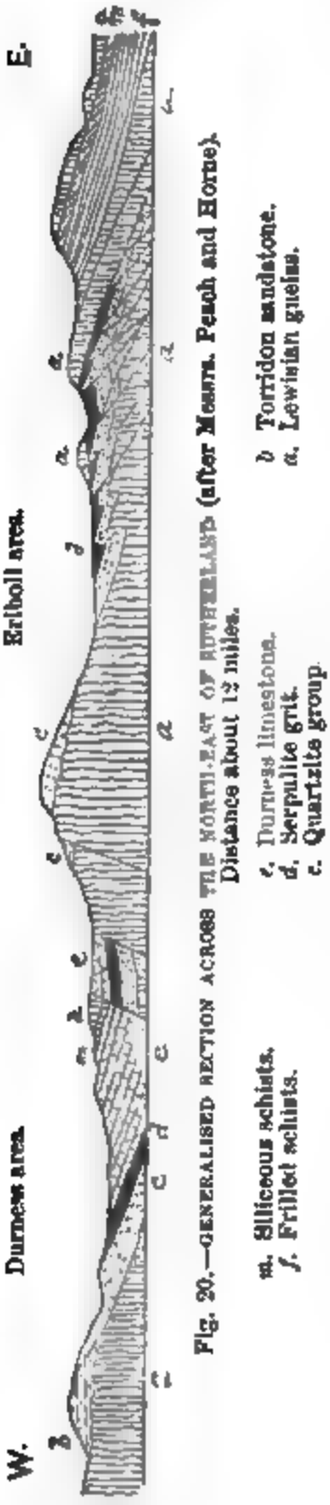


Fig. 20.—GENERALISED SECTION ACROSS THE NORTH-EAST OF SUTHERLAND (after Messrs. Peach and Horne). Distance about 12 miles.

Mr. Marr remarks that "an examination of the Skiddaw slate series shows that it is a group of deposits of great diversity of character folded violently on a large and small scale; the uppermost beds, which are fossiliferous, represent part of the Tremadoc and the whole of the Arenig series of North Wales. These beds are folded in boat-shaped synclines among what is probably a very much greater thickness of older rocks, the palæontology of which is practically unknown. It yet remains to discover the ages of these rocks, forming perhaps the greater bulk of the Skiddaw slate formation, and this is a task which may well occupy the attention of local geologists for many years to come.

The only locality indeed where graptolites of Tremadoc species have yet been found is Barth near Keswick, and the forms enumerated by Miss G. L. Elles in 1898 are *Bryograptus Kjerulfi*, *B. ramosus*, *B. Callavei*, *Clonograptus tenellus*, and *Cl. flexilis*.

5. *Scotland*

In the north-west of Scotland Cambrian rocks flank the eastern side of the tract occupied by the Lewisian gneiss and Torridonian sandstone, all the way from Durness and Eriboll on the north coast of Sutherland down to the island of Skye. Before the discovery of *Olenellus* in these rocks they were supposed to be of Ordovician age.

In the north of Sutherland there are two tracts of Cambrian, the relative positions of which are shown in Fig. 20. The beds of the Durness area are arranged in the form of a basin truncated on the eastern side by a fault which brings them against the Archæan gneiss; on the west they

are seen to rest unconformably on this gneiss and on the red Torridon sandstone. The Durness basin is separated from that of Loch Eriboll by a prominent ridge of Archæan gneiss, which, however, bears an outlier of the Ordovician basement beds. The Eriboll area exhibits the same series as that of Durness, but they are crushed and faulted in a remarkable manner, and are cut off on the east by a *thrust-plane*, which actually carries some of the Archæan gneiss over the newer Ordovician series, so that here the ordinary test of age by superposition becomes useless.

Before the existence of this thrust-plane was realised the structure of the northern Highlands was completely misunderstood and the eastern gneiss was supposed to be newer than the fossiliferous rocks of Loch Eriboll. It was not till 1883 that the accuracy of Nicol's view was demonstrated by Professor Lapworth (*Geol. Mag.* Dec. 2, vol. x. p. 120).

The total thickness of the beds composing the Cambrian system of Scotland is estimated as at least 2000 feet, but the upper limit is not reached, being everywhere concealed beneath the masses of crushed and sheared rock which have been carried westward on to and over the Cambrian strata. The exposed portion is divisible into two series, an arenaceous below and a calcareous series above. These can also be subdivided as follows:—

Calcareous series or Durness limestone, 1500 feet	3. Gray limestones, some dark and some light gray, grouped into three stages; many fossils throughout. 2. Dolomitic limestones, gray, white, mottled, and pink, with some beds of chert. The Sangomore and Sailmhor groups. Few fossils. 1. Argillaceous limestones, white and gray, some massive and some flaggy. No fossils except *Salterella*.
Arenaceous series, 580 feet	3. Dolomitic grits with *Salterella* (Serpulite grit), with calcareous mudstones (Fucoid beds) below. 80 feet. 2. Fine-grained quartzites perforated by worm burrows (pipe rock). 300 feet. 1. Coarse flaggy grits and quartzites, with a basement bed of brecciated conglomerate. 200 feet.

The most abundant fossils in the Durness limestone are Cephalopoda—*Orthoceras*, *Piloceras*, *Lituites*, and *Nautilus*. Next in number are Gastropoda, but bivalves (Lamellibranchia and Brachiopoda) are not rare. The coral *Archæocyathus* is of frequent occurrence, as are also sponges of the genus *Calathium* or *Archæoscyphia*.

In 1891 fragments of *Olenellus* (*O. Lapworthi*) and specimens of *Hyolithes* were found in the Serpulite grits and Fucoid beds of Ross, proving them to be of Lower Cambrian age. Hence it is probable that the lower part of the Calcareous series is of Middle

Cambrian age (Paradoxidian), but the higher and more fossiliferous part is of Upper Cambrian age, corresponding to the Upper Lingula flags and Tremadoc slates of Wales.

Still more recently the Cambrian succession in Skye has been worked out by Mr. C. T. Clough, who found that the same subdivision could be made as in Durness. Moreover, the Olenellus fauna was again discovered in the Fucoid beds at Tokavaig and Ord. No fossils, however, could be found in the lower part of the Durness limestone, the thickness of which to the top of the Sailmhor group Mr. Clough estimates at 830 feet. But higher beds are found in Strath, and in 1898 these yielded many fossils, including *Calathium* and *Archæoscyphia;* a trilobite of the genus *Solenopleura; Orthisina festinata* and *O. striatula;* a bivalve, *Euchasma Blumenbachia;* species of *Pleurotomaria, Murchisonia, Maclurea,* and *Holopea,* with *Piloceras, Orthoceras,* and *Trocholites.*

6. *Ireland*

Rocks which may be of Cambrian age occur in the counties of Dublin, Wicklow, and Wexford, but as they have yielded no fossils except worm tracks, the burrows known as *Histioderma* and the wrinkled markings called *Oldhamia,* their exact age is a matter of uncertainty, and they are thought by some to be of the same age as the rocks of the Longmynd, *i.e.* Pre-Cambrian.

A good section is presented by the cliffs at Bray Head (13 miles south-east of Dublin). Here, at the northern end, are red, purple, and green slates and grits, succeeded on the south by alternating grits and shales. The beds are bent into numerous sharp folds, so that the real thickness is much less than appears at first sight. Jukes and Du Noyer estimated the exposed succession at between 3000 and 4000 feet, but the base is not shown, neither is the top actually visible. These rocks are also well exposed on the coast of Howth, east of Dublin, where they include some remarkable breccias, but their base is not seen.

7. *Continental Equivalents*

Rocks of Cambrian age and more or less resembling those of England and Wales have been discovered in Spain, in Southern France (Languedoc), in the Ardennes (borders of France and Belgium), and in Bohemia. Students cannot be expected to master the details of all these areas, but it is necessary that they should know something of the remarkable set of Cambrian

deposits which exists in Norway, Sweden, and Northern Russia, for in these countries the Cambrian strata occur in broad, flat-lying sheets as originally deposited, and are so little altered that they have more the aspect of our Mesozoic clays, shales, and sandstones than of Palæozoic rocks. Moreover, those of Scandinavia present a complete succession of highly fossiliferous beds, and yet their thickness is only a few hundred feet.

Scandinavia.—It is interesting to note that, as in England, the Cambrian series of this region consists everywhere of a lower arenaceous division and an upper argillaceous division, the lower being from 350 to 550 feet thick and the upper from 200 to 400 feet. The system is most fully developed in Sweden, and especially in the districts of Scania and Westrogothia, where there is the following succession in descending order (slightly altered from Linnarsson and Brogger).

IV. *Passage beds* (thickness about 50 feet = Tremadoc).
- 2. Ceratopyge limestone, with *C. forficula.*
- 1. Dictyograptus shales, with *Dictyograptus* and *Obolella Salteri.*

III. *Olenus shales* in seven zones, with three bands of limestone, thickness from 70 to 200 feet = Lingula flags.
- Zones 4 to 7 contain *Parabolina spinulosa* and *Olenus* (*Peltura*) *scarabæoides.*
- Zone 3 contains *Beyrichia Angelini* and *Agnostus cyclopyge.*
- Zones 2 and 1 have *Olenus truncatus*, *O. gibbosus*, and *Ag. pisiformis.*

II. *Paradoxides shales*, divisible into three principal zones, and from 80 to 160 feet thick. Homotaxial with Menevian and Solva beds.
- 3. The Andrarum limestone with 5 feet of shale above ; *Agnostus lævigatus*, *Paradoxides Forchhammeri*, and *Orthis Hicksi.*
- 2. Zone of *Par. Davidis* and *Par. ölandicus.*
- 1. Zone of *Par. Tessini* with the exsulans limestone at base containing *Conocoryphe exsulans* and *Par. palpebrosus.*

I. *Olenellus beds*, chiefly sandstones homotaxial with the Hartshill quartzite and Caerfai beds, 350 to 550 feet.
- 3. Sandy shales with *Olenellus Kjerulfi* and *Arionellus primævus* (5 to 10 feet).
- 2. Fucoid sandstone with *Obolella favosa*, 200 to 350 feet.
- 1. Eophyton sandstone with *Mickwitzia monilifera* and the markings called *Eophyton* and *Cruziana*, 150 to 200 feet.

The basal sandstones rest unconformably upon the Archæan gneisses.

Russia.—In the Baltic provinces of Russia there is a still more remarkable development of the Cambrian system. The arenaceous division is partly replaced by blue clay, and the black trilobite shales are absent. The succession is as follows :—

	Feet.
6. Glauconitic sand with *Obolus* and *Siphonotreta*	10
5. Shales with *Dictyograptus* and *Bryograptus*	20
4. The Ungulite sandstone full of *Obolus Apollinis* and other minute Brachiopods	4
3. Alternating clays and sandstones with *Olenellus Mickwitzi*, *Mickwitzia monilifera*, and a *Scenella*	50
2. The blue clay, without fossils	300
1. Ferruginous sandstones, resting on granitoid rock	300
	684

Professor F. Schmidt has pointed out that the base of the Ungulite sandstone is sharply divided from the beds below, and sometimes contains pebbles derived from them. Hence there appears to be a gap at this point, which will account for the complete absence of any representatives of the Paradoxides and Olenus shales, unless the thin band of Ungulite sandstone is a partial equivalent of the latter. The underlying clays and sandstones are evidently the equivalents of the Fucoid and Eophyton sandstones, while the two highest members are comparable with the beds which occupy the same position in Sweden.

Contemporary Volcanic Rocks

It has been mentioned on p. 51 that Sir A. Geikie does not believe that the so-called basal conglomerates in Wales are really unconformable to the underlying volcanic rocks, and consequently he considers the latter to be of Cambrian age. As they were only briefly referred to under the head of Pre-Cambrian, a few more particulars may here be given concerning them.

Near St. Davids the predominant members are volcanic tuffs, varying in colour from purple and red to pink, green, and yellow, and varying in texture from coarse agglomerates to fine silky schists, in which the original tufaceous character is almost obliterated by the superinduced schistosity. The majority are of a basic nature with about 50 per cent of silica, but many contain fragments of more acidic lavas. With these tuffs and agglomerates are interbedded sheets of basic lava (diabase), and these sheets thicken to the south-west as if the main vents lay in that direction.[14] There are also intrusions of both basic and acidic lava.

In Caernarvonshire the oldest rocks are quartz porphyries (or rhyolites), and these are succeeded by conglomerates, cleaved tuffs, and other sediments which enclose much volcanic material, but no actual lava-flows have been detected.

In Merionethshire the great volcanic outbursts of the Ordovician period were preceded by eruptions in Upper Cambrian times.[15]

Messrs. Lake and Reynolds have traced a band of andesitic lava in the Upper Lingula flags near Dolgelly, and also a rhyolite resting on the summit of the Tremadoc slates. Again in the great mass of Rhobell Fawr (see map, Fig. 14), which rises to a height of 2400 feet, volcanic agglomerates and tuffs rest on the highest Lingula flags and appear to take the place locally of the whole Tremadoc series. The rock-fragments in the agglomerates are chiefly of andesitic lava, some basaltic and some trachytic, and there are associated intrusive sills of similar material.

Physical Geography of the Period

Any attempt to restore the geographical conditions of the early Palæozoic periods, to realise the general position of the land areas, and consequently the limits of the sea, must always be a task of great difficulty. The rocks which we can study are as a rule only so many isolated portions of some ancient sea-floor, and the traces of contemporaneous land are only to be looked for where some particular set of strata is wanting, and where there is consequently a gap in the succession. But there are such large areas where the rocks of the earlier systems are buried deep beneath those of newer times, that the evidence is generally of a slender and fragmentary nature.

Nevertheless wherever rocks of Lower Palæozoic age can be traced over a considerable area, some indications of the direction from which the sediment was transported can generally be found, and this is certainly a point which the student of Palæozoic rocks should have before his mind. Present attempts at definite geographical restoration must be tentative and more or less hypothetical, but they are useful as helping to fix certain facts in the mind, and more evidence will be obtained as fresh discoveries are made, and these may eventually enable us to form fairly definite ideas of the varying phases of European geography during early Palæozoic time.

It will therefore be worth while mentioning such evidence as we possess at the present time for answering the question, Where was the land which furnished the materials of the Cambrian rocks of Britain?

In the first place some general considerations are suggested by a comparison of the deposits in Wales, England, Sweden, and Russia. The enormous thickness of the Welsh Cambrians, which have a maximum thickness of about 11,000 feet, as compared with a possible 3000 feet in Warwickshire, less than 1000 feet in Sweden, and only 680 feet in Russia, is a point of great significance; but the inference to be drawn from these figures depends on other

stratigraphical facts. If the lower beds were not represented in the Swedish and Russian succession, it might be inferred that the north of Europe was a land area during the earlier part of the period, and was gradually submerged by the waters of a sea which spread over it from the south-west, and this view was actually suggested in 1876 before the *Olenellus* fauna was recognised in Europe. The facts as we now know them, however, will not allow of such an inference; the Swedish succession is as complete as that of Warwickshire or South Wales, and the difference in thickness is caused mainly by the great increase in the amount of sandy material in the Cambrian sediments as we pass from east to west. Moreover, this increase of sandy material shows itself not only in the lower or arenaceous division (Lower and Middle Cambrian), but also in the upper division, for in Wales a large part of the Lingula flags consists of flagstones and sandstones, which become coarse quartzose grits as they are followed through Caernarvon.

As the Swedish geologist Linnarsson wrote in 1876, "The facts rather tend to show that most of the Swedish Cambrian rocks were deposited in a deeper sea and farther from land than the British." He points out that the small thickness of the *Olenus* beds over such a large area in Sweden can only be explained on this view, for they are so thin compared with the Lingula flags of Wales that the rate at which sediment was accumulated in Wales must have been fifty or sixty times as rapid as it was in Sweden. This must have been due to the much greater proximity of land, while all the facts connected with the Upper Cambrians of Sweden lead us to infer that they were deposited in a deep sea and far from land.

We may therefore safely conclude that, so far as the British area is concerned, the land from which the greater part of the Cambrian sediments was derived lay to the west of Wales, and that there was a wide open sea to the eastward stretching from our midland counties across the North Sea and Southern Sweden into the Baltic provinces of Russia. Further, the small thickness of Lower Cambrian in Scotland and the great thickness of limestone above it prove that there was a clear and open sea for some distance in that direction also. Hence it is to the west and south-west of Wales that we may look for indications of land, and we shall find that there are at least two districts in which such indications exist.

The first district is that of Anglesey and Caernarvon. We have seen (pp. 81, 82) that when the Cambrian rocks are traced westward through Caernarvon their thickness rapidly diminishes, the lower beds thinning out and the Tremadoc beds eventually overlapping the Lingula flags, till in Anglesey they rest with a basal conglomerate on the Archæan schists. From these facts it seems a neces-

sary inference that Anglesey was part of a land area throughout the greater portion of Cambrian time, and further, looking to the great thickness of the Cambrian sediments, that the land area was of a continental nature, with large rivers carrying down the detritus of a mountainous country on which subaerial agencies were actively at work. As to the general trend of this land we can be fairly sure that its coast-line ran either westward or south-westward from Caernarvon, because it must have passed well outside Pembrokeshire. If the Bray Head rocks are Pre-Cambrian then the coast probably ran to the south-west through what is now the Irish Sea; but if they are Cambrian, as seems most likely, then it must either have passed westward to the north of Dublin, or else Anglesey was connected with a land that lay to the north-west.

The second district is Brittany, where no Lower Cambrian fauna had yet been found,[16] and where the Upper Cambrian consists of red and purple conglomerates and pebbly felspathic gritstones, which are overlain conformably by a thick mass of red slates without fossils. Both divisions are thickest in the south, thinning out entirely to the north-west, and it is only eastward on the borders of Mayenne and Maine that they pass into shales and sandstones with *Lingulella*.

From this we may infer that there was a tract of land between Brittany and Ireland, and the absence of Cambrian rocks in Cornwall makes it probable that it included much of that county, and that its coast-line may have stretched thence to the north-west till it curved round to meet a more northern coast-line.

If these inferences are correct, the Cambrian rocks of Wales will have been deposited in a broad bay or strait having land on its south-western and north-western sides, a geographical arrangement which would be likely to favour the accumulation of a thick mass of sediment.

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[9] See *Quart. Journ. Geol. Soc.* vol. xxxvi. p. 238 (1880).

[10] Professor Lapworth's "Geology of the Birmingham District," *Proc. Geol. Assoc.* vol. xv. p. 313, a memoir which should be consulted by every student.

[11] See Professor Groom in *Quart. Journ. Geol. Soc.* vol. lv. p. 157 *et seq.* (1899).

[12] Dr. C. Callaway in vol. xxxiii. p. 652 (1877).

[13] J. E. Marr, "Notes on the Skiddaw Slates," *Geol. Mag.* ser. 4, vol. i. p. 122.

[14] Geikie's *Ancient Volcanoes of Great Britain*, vol. i. p. 152.

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CHAPTER VIII

THE ORDOVICIAN SYSTEM

Nomenclature.—The grounds on which this system has been established have already been explained (see p. 65). It is the UPPER CAMBRIAN of Sedgwick and the LOWER SILURIAN of Murchison and the Geological Survey. In the British Isles it is divisible into three series of strata :—

3. Upper Ordovician or Bala series.
2. Middle Ordovician or Llandeilo series.
1. Lower Ordovician or Arenig series.

The names are taken from places in Wales where the several series are well developed, *i.e.* the Arenig Mountains in Merioneth, the town of Llandeilo in Caermarthenshire, and the town of Bala in Merioneth. This succession was first established in North Wales by Sedgwick. Part of it was studied at the same time in Shropshire and Caermarthen by Murchison, who described the local equivalents of the Bala series under the name of Caradoc sandstone, and after their identity had been demonstrated the beds were for a time called the Bala and Caradoc series.

LIFE OF THE PERIOD

The line of separation between the Cambrian and Ordovician systems is drawn at the base of the Arenig rocks in Wales, because there is a palæontological break between them and the Tremadoc slates ; no fewer than 40 new genera and 133 new species appear in the Arenig, while only 23 genera and 16 species pass up from the Tremadoc. It is true there is a similar break between the Arenig and Llandeilo faunas, only 9 species passing from one to the other ; but the two series are united by having many genera

of graptolites and trilobites in common, the general aspect of the Arenig and Llandeilo fossils being in fact very similar.

Taken as a whole, the special features of the Ordovician fauna are—(1) the abundance of compound graptolites belonging to the families *Dichograptidæ*, *Dicellograptidæ*, *Glossograptidæ*, *Leptograptidæ*, and *Diplograptidæ*. Of these the first includes the following genera—*Dichograptus*, *Tetragraptus*, *Didymograptus*, and *Phyllograptus*; in the Dicellograptidæ are *Dicellograptus* and *Dicranograptus*. The Glossograptidæ include *Glossograptus* and *Lasiograptus*.

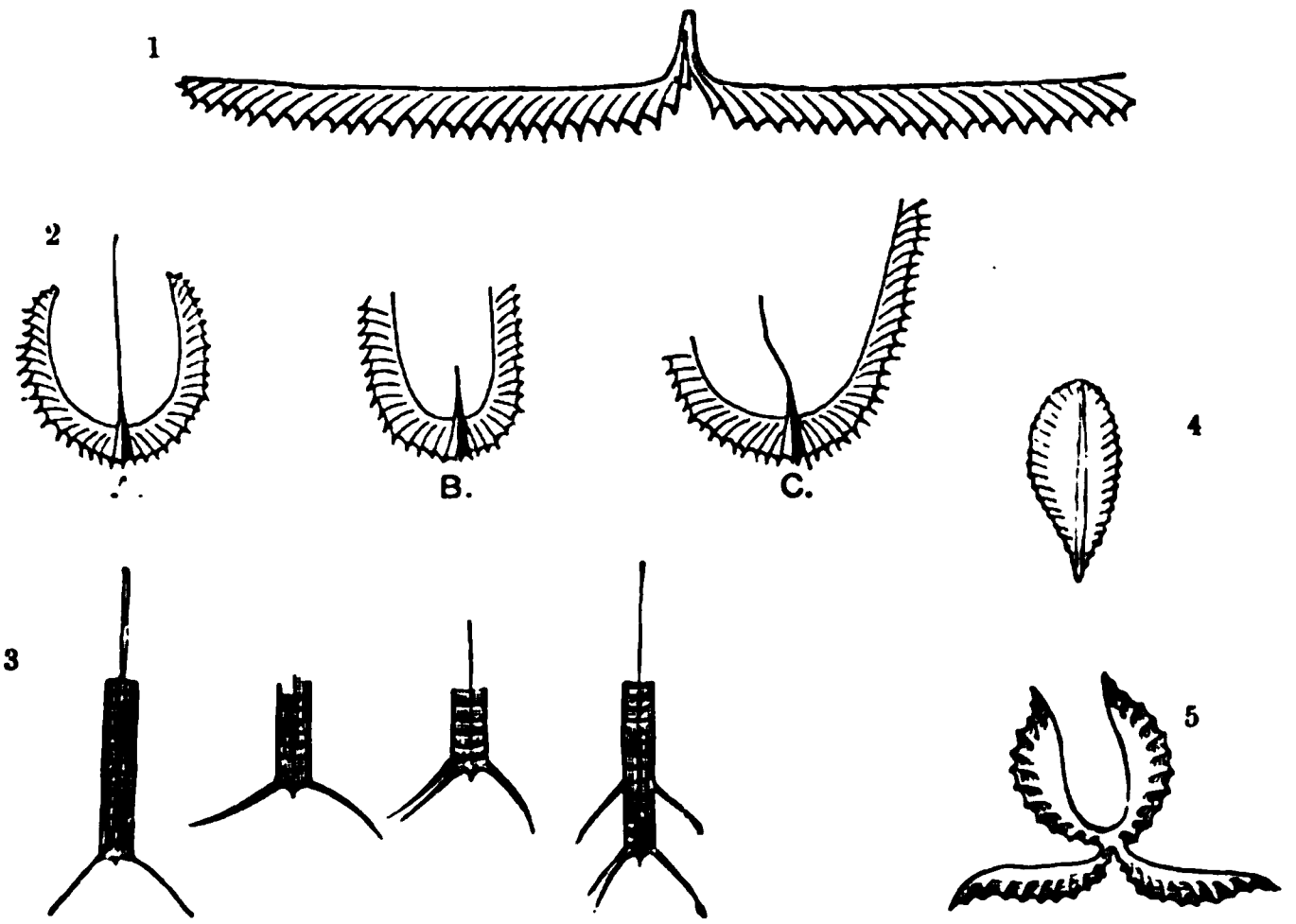

Fig. 21.—GROUP OF ARENIG AND SKIDDAW GRAPTOLITES.

1. Didymograptus patulus.
2. Didymograptus gibberulus.
3. Cryptograptus antennarius.
4. Phyllograptus typus.
5. Tetragraptus bryonoides.

The Leptograptidæ include *Leptograptus* and *Cœnograptus*, while *Diplograptus*, *Cryptograptus*, and *Climacograptus* belong to the Diplograptidæ.

(2) The appearance of many new trilobite genera—**Æglina*, *Acidaspis*, *Ampyx*, **Amphion*, *Asaphus*, *Calymene*, *Cheirurus*, *Encrinurus*, **Harpes*, *Homalonotus*, *Illœnus*, *Lichas*, *Phacops*, **Placoparia*, *Proëtus*, *Remopleurides*, *Staurocephalus*, **Stygina*, and *Trinucleus*, those with an asterisk not surviving this period.

(3) The abundance of Cystideans, eight genera, and twenty-three species, in the Bala group.

(4) The abundance of Orthidæ.

The following genera of Brachiopoda make their appearance in this period—**Acrotreta*, *Atrypa*, *Chonetes*, *Leptæna*, **Orthisina*, *Rhynchonella*, *Siphonotreta*, *Spirifer*, *Strophomena*, and *Triplesia*.

The restriction of certain species of graptolites to certain bands of rock allows of the establishment of zones characterised by groups of graptolites, which thus become valuable aids in determining the age and succession of the beds, especially where these are folded and faulted.

The following are the principal species which characterise the several divisions of the Ordovician system :—

Fossils of the Lower or Arenig Series

Hydrozoa. Tetragraptus bryonoides, T. serra, Trigonograptus truncatus, Phyllograptus typus, Ph. angustifolius, Diplograptus dentatus, D. bimucronatus, Didymograptus bifidus, D. patulus, Glossograptus ciliatus.

Fig. 22.—TWO ARENIG MOLLUSCA.

a. Palæarca amygdalus. *b*. Euomphalus corndensis.

Crustacea. Ogygia Selwyni, Æglina binodosa, Æ. caliginosa, Calymene parvifrons, Trinucleus Gibbsi, Placoparia cambrensis, Caryocaris Wrighti.

Brachiopoda. Lingula attenuata, Monobolina plumbea, Orthis alata.

Pelecypoda. Redonia anglica, Palæarca amygdalus.

Gastropoda. Euomphalus corndensis, Pleurotomaria llanvirnensis, Conularia Homfrayi, Hyolithes (Theca) vaginula.

Cephalopoda. Orthoceras sericeum.

Fossils of the Middle or Llandeilo Series

Radiolaria. Species of Styptosphæra, Spongoplegma, Diploplegma, Stauroplegma, Haliomma, Dorysphæra, Doryplegma, Triplosphæra.

Foraminifera. Saccamina Carteri.

Hydrozoa. Didymograptus Murchisoni, Diplograptus foliaceus, Dicellograptus divaricatus, and D. sextans, Cœnograptus gracilis, Dicranograptus ramosus, and D. formosus, Climacograptus cælatus, Cl. perexcavatus, Glossogratups Hincksi.

Crustacea. Asaphus tyrannus, Ogygia Buchi, Ampyx nudus, Trinucleus fimbriatus, Agnostus M'Coyi, Acidaspis Jamesi.

Brachiopoda. Lingula brevis, Orthis alata, O. confinis, Siphonotreta micula (ranges into Bala).

Lamellibranchia. Maclurea Logani, M. magna, Ophileta compacta, Bellerophon perturbatus (passes to Bala).

Cephalopoda. Orthoceras Avelinei.

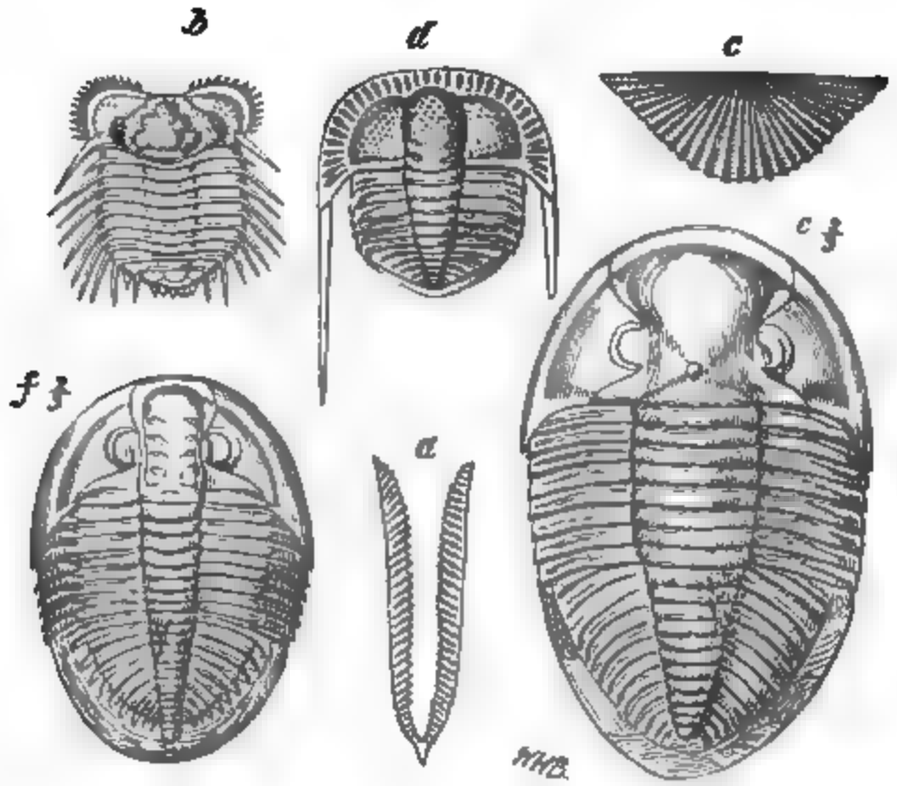

Fig. 23.—GROUP OF ARENIG AND LLANDEILO FOSSILS.

a. Didymograptus Murchisoni.
b. Acidaspis Jamesi (Irish).
c. Orthis alata (Arenig).
d. Trinucleus fimbriatus.
e. Asaphus tyrannus.
f. Ogygia Buchi.

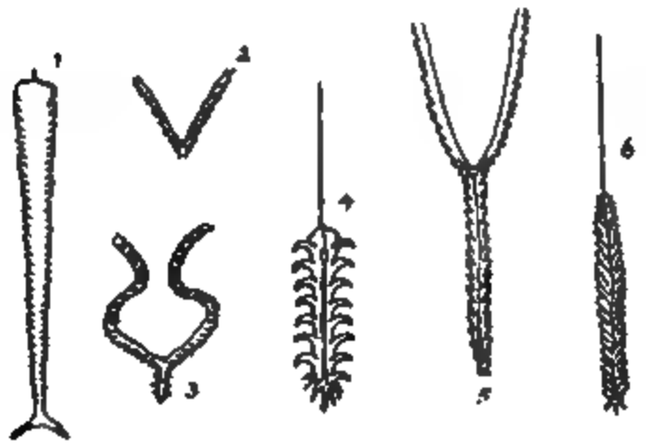

Fig. 24.—GROUP OF LLANDEILO AND BALA GRAPTOLITES.

1. Climacograptus bicornis.
2. Dicellograptus sextans.
3. Dicellograptus ziczac.
4. Glossograptus Hincksi.
5. Dicranograptus ramosus.
6. Diplograptus foliaceus.

Fossils of the Upper or Bala Series

Actinozoa. Favosites crassa, Aulacophyllum mitratum.

Hydrozoa. Climacograptus Wilsoni, Dicranograptus Clingani, Pleurograptus linearis, Dicellograptus anceps, D. complanatus, D. truncatus, Leptograptus flaccidus.

Echinoderma. Rhaphanocrinus basalis, Echinosphæra aurantium, Sphæronis munitus, S. Litchi, Hemicosmites rugatus.

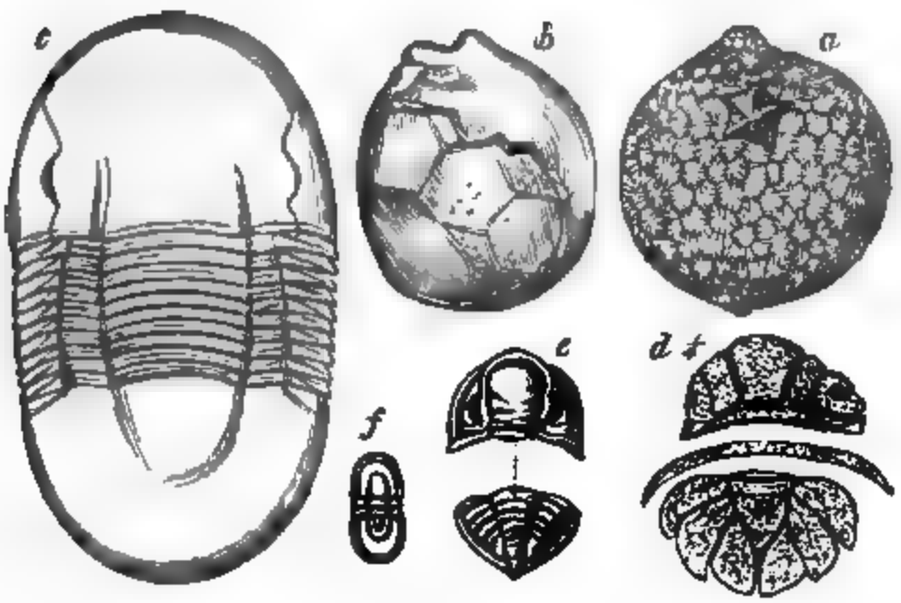

Fig. 25.—GROUP OF BALA FOSSILS.

a. Echinosphæra aurantium.
b. Sphæronis munitus.
c. Illænus Davisi.
d Lichas hibernicus.
e. Phacops apiculatus.
f. Agnostus trinodus.

Crustacea. Trinucleus concentricus, T. seticornis Illænus Davisi, I. Bowmanni, Homalonotus bisulcatus, Phacops apiculatus, P. Brongniarti, Lichas laxatus, L. hibernicus, Staurocephalus clavifrons (=S. globiceps).

Bryozoa. Monticulipora favulosa, M. petropolitana, Phyllopora Hisingeri, Ptilodictya costellata.

Brachiopoda. Orthis actoniæ, O. flabellulum, O. calligramma, O. biforata, O. sagittifera, O. vespertilio, Leptæna (Plectambonites) sericea, Strophomena expansa, S. grandis, Trematis corona.

Lamellibranchia. Ctenodonta varicosa, Palæarca edmondiiformis, Modiolopsis obliqua, M. orbicularis.

Gastropoda. Holopea concinna, Cyclonema crebristria, Murchisonia simplex, Raphistoma lenticularis, Tentaculites anglicus, Hyolithes (Theca) triangularis, Bellerophon nodosus.

Cephalopoda. Cyrtoceras sonax, Orthoceras vagans.

Range and Relation to Rocks below

Where the Upper Cambrian series exists the Ordovician rocks are generally found in conformable sequence, the only known

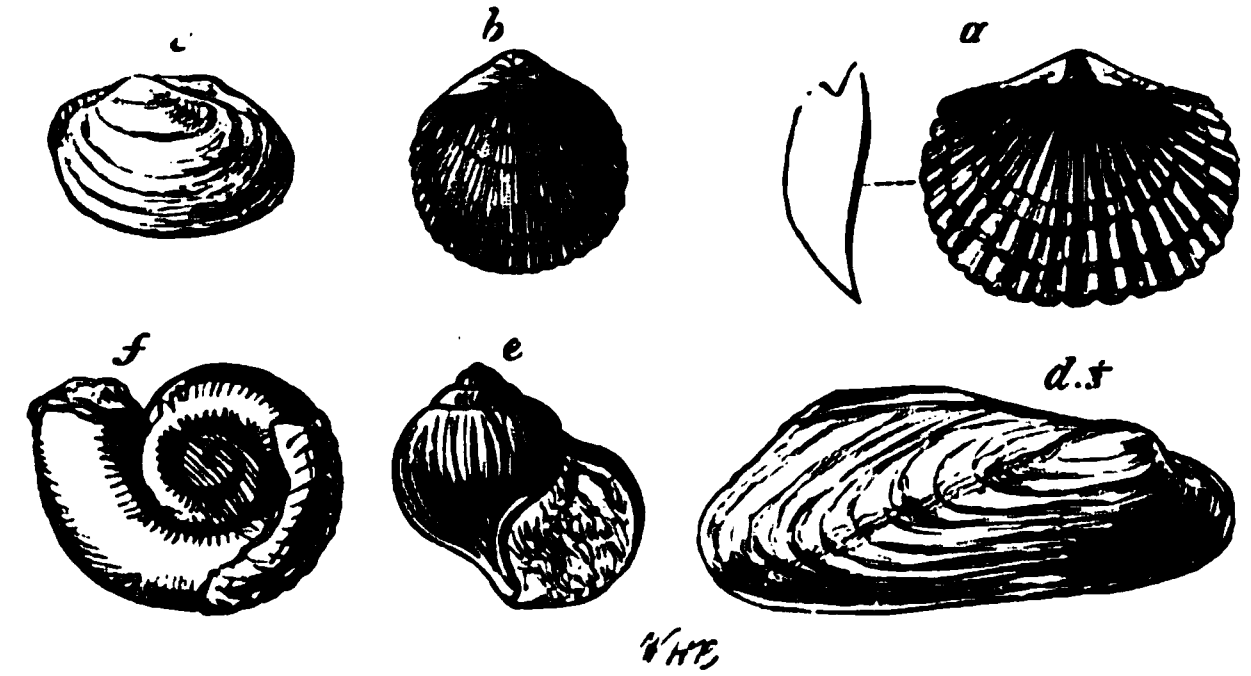

Fig. 26.—GROUP OF BALA FOSSILS.

a. Orthis flabellulum.
b. Orthis elegantula.
c. Ctenodonta semitruncata.
d. Modiolopsis expansa.
e. Holopea concinna.
f. Lituites hibernicus.
g. Trinucleus concentricus.
h. Lituites cornuarietis.
m. Orthis calligramma.
n. Orthis vespertilio.

exception being in Merioneth, where for a small space the Arenig series rests on the Dolgelly beds, owing probably to a contemporaneous erosion of the Tremadoc shales.

Ordovician rocks occupy a much larger area of the surface both in Great Britain and in Ireland than do the Cambrian rocks. Thus in Wales they form a continuous tract of considerable breadth

stretching from Pembrokeshire in the south through Caermarthen, Cardigan, Radnor, Montgomery, Merioneth, and Denbigh. Passing eastward beneath the lower beds of the Silurian in Montgomery, they rise again to the surface in Shropshire, and form the Corndon and Caradoc tracts on either side of the Longmynd Hills.

Ordovician fossils were found by Professor Sedgwick in Cornwall, but the stratigraphy of the rocks containing them has not yet been worked out.

Rocks of this age occupy a large part of the Lake District, where they were first studied by Sedgwick. The Isle of Man is an isolated fragment of this Cumbrian area, while to the eastward, in Yorkshire, some small inlying exposures occur, proving the extension of Ordovician rocks beneath the newer strata in that direction.

In the south of Scotland, Ordovician and Silurian rocks range across from Wigtown to Berwickshire, and form the mass of the southern highlands, their northern boundary being generally the great line of fault which runs from Girvan in Ayr to the Lammermuir Hills. It is believed that strata of Ordovician age are included among the metamorphic rocks of the central highlands, but no definite succession has yet been made out in that region.

Ordovician rocks occur in many parts of Ireland and exhibit several different facies, one of these facies being found in the north-west (Galway, Mayo, Donegal, and Londonderry), another in the north-east (Down, Cavan, and Meath), another in the south-east (Wicklow, Wexford, and Waterford, with extensions into Clare and Tipperary).

1. *South Wales*

In South Wales the areas where the Ordovician succession is best exposed and has been most fully investigated are the western and central parts of Pembrokeshire, near St. Davids and Haverfordwest (see map, Fig. 13, p. 72).

Arenig Series.—This series was first recognised near St. Davids by Dr. Hicks, who divided it into Lower, Middle, and Upper stages, and estimated its total thickness at about 4000 feet, but the ground is much faulted, and this may be an over-estimate.

The Lower Arenig consists of fine black slates and shales, which are best exposed in Ramsey Island, where they have yielded *Didymograptus extensus*, *Phyllograptus stella*, *Trigonograptus ensiformis*, and *T. truncatus*. Some of the same beds are seen in Whitesand Bay on the mainland, but are faulted against the Tremadoc slates, and some of the fossils recorded by Dr. Hicks seem

CORRELATION TABLE OF ORDOVICIAN ROCKS.

	South Wales.	North Wales.	Shropshire.	Lake District.	Girvan.	Moffat.
Bala Series.	Upper Bala, B. limestone, Lower Bala, 3000 feet.	Upper Bala, B. limestone, Lower Bala, 4000 feet.	Not exposed. Trinucleus shale and Acton Beds, Caradoc sandstone, 4000 feet.	*Bala Series.* Ashgill Beds, Sleidale Beds, Corona Beds, 3000 feet.	*Ardmillan Series.* 3000 feet. Drummuck Beds. Shalloch Beds. Whitehouse and Ardwell Beds. Balclatchie Beds.	*Hartfell Shales.* Upper shales, Lower shales, 100 feet.
Llandeilo Series.	Upper group, Middle group, Lower group, 2500 feet.	*Llandeilo Beds.* Not yet divided, 2000 feet.	Cænograptus Beds, Meadowtown Beds, Weston Beds, 3000 feet.	*Borrowdale Series.* Rhyolites, andesites, and volcanic ashes, 10,000 feet.	*Barr Series.* Stinchar group, Kirkland Beds. 300 feet. Unconformity.	*Glenkiln Shales.* Cænograptus Beds, Chert Beds, 70 feet.
Arenig Series.	Upper Arenig, Middle Arenig, Lower Arenig, 3000 feet.	Upper Arenig, Garth grit, 1200 to 5000 feet.	Volcanic Beds, Black shales, Flagstones, 3000 feet.	7000 feet. Part of the Skiddaw slates. Garth grit.	*Arenig Series.* Over 1500 feet, Chert Beds and shales, volcanic rocks. Base not seen.	*Arenig Beds.* Chert Beds. Base not seen.

to have been obtained from the Tremadocs close to this fault. He believed this group to be about 1000 feet thick.

The Middle Arenig beds are a series of black slates and flagstones with some beds of gritty sandstone, and they have yielded many of the characteristic Arenig trilobites, *Ogygia peltata*, *Æglina grandis*, *Trinucleus Gibbsi*, and *Ampyx Salteri*, and the graptolites *Tetragraptus serra*, *T. crucialis*, and *Didymograptus patulus*.

The Upper Arenig consists almost entirely of fine black slaty shales with a thickness of nearly 1500 feet. Fossils are not everywhere common nor well preserved, but a quarry at Llanvirn has yielded a number of species, including many trilobites of the genera *Placoparia*, *Phacops*, *Trinucleus*, *Illœnus*, *Calymene*, and *Burrandia*, with the graptolites *Diplograptus dentatus*, *Didymograptus bifidus*, and *Glossograptus ciliatus*.

Llandeilo Series.—North of St. Davids the Llandeilo flags succeed the Arenig series, and were divided into three stages by Dr. Hicks in 1875.

	Feet.
Upper stage—black slates and flags, with *Ogygia Buchi* . .	1000
Middle stage—calcareous slates and flags, with *Asaphus tyrannus* and *Diplograptus foliaceus*	800
Lower stage—black slates and felspathic tuffs, with *Didymograptus Murchisoni*	500-1000
	About 2500

The Llandeilo flags are found again to the south of the Archæan and Cambrian areas near Haverfordwest, and thence they range eastwards through Narberth, Caermarthen, and Llandeilo. This district has been recently examined by Messrs. Marr and Roberts, who establish the following succession :—[1]

3. Shales with *Dicranograptus ramosus* and *Ogygia Buchi*.
2. Llandeilo limestone with *Asaphus tyrannus*.
1. Shales with *Didymograptus Murchisoni*.

The Llandeilo limestone is best seen at Narberth and Llandeilo, where it is a compact black limestone, but elsewhere it is reduced to a line of calcareous concretions. Besides the *Asaphus*, *Trinucleus favus*, *Calymene cambrensis*, *Leptæna sericea*, and a few corals, have been found in it.

Still farther east, at St. Clears near Caermarthen, Professor Lapworth found a good exposure of black shales full of graptolites which seem to be of Upper Llandeilo age. The species are *Dicranograptus formosus*, *Diplograptus foliaceus*, *Climacograptus cælatus*, *and C. perexcavatus*. At Pwllaca near Llandeilo he found the Lower Llandeilo shales with *Didymograptus Murchisoni*.

Bala Series.—By Haverfordwest and Narberth the Bala beds succeed the Landeilo shales, one passing into the other, the former series comprising the following stages, according to Messrs. Marr and Roberts :—

5. Green shales with calcareous bands, containing *Phyllopora Hisingeri, Trinucleus seticornis* .	= Upper Bala.
4. Gray shales with *Phacops Brongniarti* . .	
3. Sholeshook limestone with *Agnostus trinodus, Philipsinella parabola, Staurocephalus clavifrons*	
2. Robertson Wathen limestone . . .	= Bala limestone.
1. Shales with *Orthis argentea* and *Siphonotreta micula*	= Lower Bala.

Murchison describes the Bala beds near Llandovery as consisting of dark sandy shales, with some calcareous bands containing *Trinucleus seticornis* and *Staurocephalus Murchisoni*. These beds are overlain by pebbly beds passing up into rocks with Lower Llandovery fossils. It is evident that what Murchison calls Bala beds here are only the upper part of that series, and that the Lower Bala stage is included in the Llandeilo of the Geological Survey section. When the graptolites are carefully collected in this district, the boundary between the Llandeilo and Bala series will be more clearly defined.

2. *North Wales*

Arenig Series.—This group was established by Professor Sedgwick, and named from the Arenig Mountains in Merioneth, but for many years the relations of the Arenig and Tremadoc series in North Wales remained very uncertain. Mr. Salter in 1853 did much to unravel the structure of the Portmadoc area and Penrhyn promontory, but it was not till 1874-5 that the base of the Arenigs was finally determined and followed through the typical area by Sir A. Ramsay and other members of the Geological Survey.[2] They then found that a bed of hard felspathic grit could be followed all round the Merioneth anticline at the base of the dark Arenig slates. This grit is known as the Garth grit, from a place south-east of Tremadoc (see p. 82).

The whole series in North Wales is so largely interstratified with volcanic rocks that it is difficult to estimate the thickness of the sedimentary beds, but in the Aran Mountains there are 500 to 600 feet of slates between the Garth grit and the lowest volcanic ashes, and probably the total thickness of the slates is from 1000 to 1200 feet. In the Aran Mountains the thickness of the included felstones and ash-beds is no less than 5000 feet, but

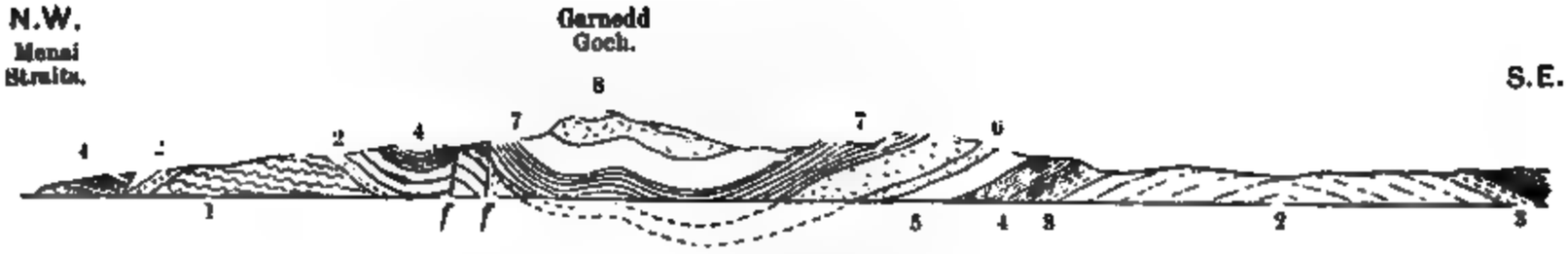

Fig. 27.—SECTION FROM MENAI STRAIT ACROSS THE SNOWDON RANGE AND THE HARLECH ANTICLINE. Distance about 30 miles.

8. Bala beds of Snowdon.
7. Llandeilo beds.
6. Arenig beds.
5. Tremadoc slates.
4. Lingula flags.
3. Menevian beds.
2. Harlech beds.
1. Pre-Cambrian.
ff. Faults.

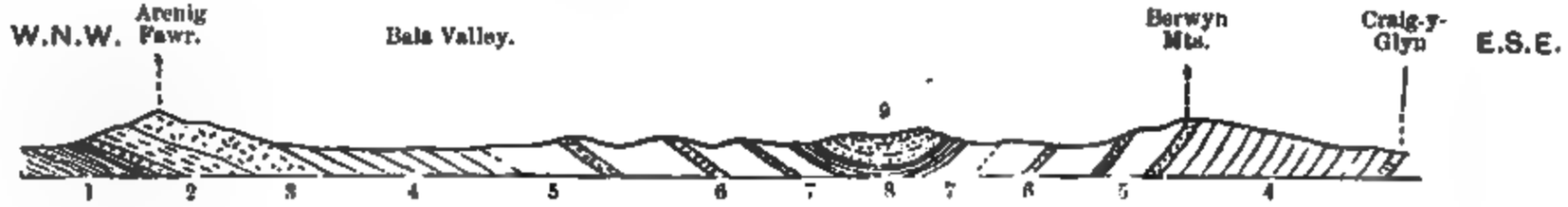

Fig. 28.—SECTION FROM THE ARENIG TO THE BERWYN MOUNTAINS. Distance about 24 miles.

9. Denbigh flags.
8. Tarannon shale.
7. Hirnant beds.
6. Bala limestone.
5. Lower Bala beds.
4. Llandeilo beds.
3. Arenig lavas.
2. Arenig shales and grit.
1. Lingula flags.

The lower section is practically a continuation of the upper one.

these rocks thin away northward and are little over 1000 feet in the typical Arenig district.

The Arenig beds extend from Cader Idris on the south through the Aran and Arenig Mountains to Manod Mawr and Moelwyn on the north, and thence by Tremadoc westward into the Lleyn promontory. To the north-west they pass beneath the Snowdon range, reappearing on the western side of that and the Carnedd Llewellyn range, and they are found again in Anglesey.

One of the best localities for seeing the Arenig beds is the promontory of Penrhyn, through which a section has been given (see Fig. 18). The position of the Garth grit, which is not more than 12 feet thick, is there shown, with the overlying black slates of Ty-Obrey, from which many fossils have been obtained, notably

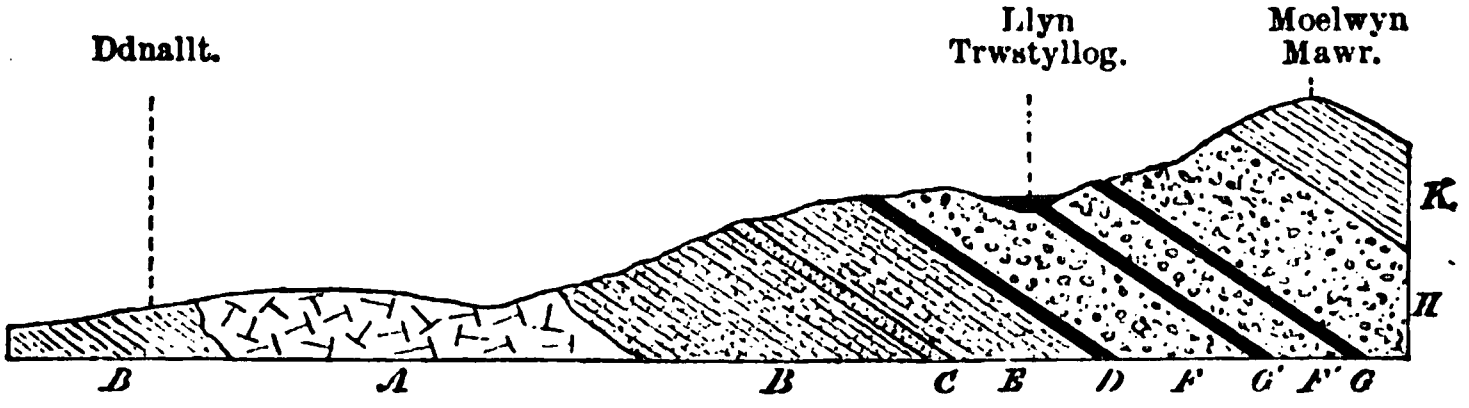

Fig. 29.—SECTION THROUGH MOELWYN (by Messrs. Jennings and Williams, by permission of the authors and the Council of the Geol. Soc.).

K. Llandeilo slates.
H, F.F. Beds of volcanic agglomerate.
G.G., D. Arenig slates.
E. Spotted flags (Arenig) with Garth grit (*C*) at base.
B. Tremadoc flags.
A. Granite.

the trilobites *Calymene parvifrons*, *Asaphus affinis*, *Æglina caliginosa*, and the graptolites *Climacograptus confertus*, *Glossograptus ciliatus*, and *Diplograptus bimucronatus*. Above these are ashy slates and ash-beds passing under the volcanic series. The fossils of the black slates show them to be of Upper Arenig age, and consequently there is only the Garth grit to represent the lower beds, but Mr. Marr informs me that he suspects the intermediate beds are cut by a fault running along the strike. This view finds confirmation in the succession found in the Moelwyn range and in Manod Mawr, where the beds above the Garth grit consist of hard spotted flags overlain by slates which do not yield the fauna of the Ty-Obrey beds, but contain *Tetragraptus*, which is a genus characteristic of the Middle Arenig.

Still farther east, near Llyn Serw, Mr. Williams has found[3] that the Garth grit rests directly on the Upper Lingula flags (Dolgelly beds) and is overlain by beds containing *Ogygia Selwyni* and *Æglina*. Here, therefore, as Sir A. Ramsay contended in 1881, there

appears to be an unconformity between the Cambrian and the Ordovician, with a local absence of Tremadoc slates.

Llandeilo Flags.—If the whole of the lower series of interbedded volcanic rocks in North Wales is correctly referred to the Arenig series,[4] it follows that the Llandeilo group must be limited to the dark shaly flags which succeed the volcanic series along the eastern side of the Aran and Arenig ranges. These beds contain very few fossils, and pass gradually up into rocks with fossils of Bala species, so that the very existence of Llandeilo flags in North Wales is at present rather inferred than actually proved. In the Moelwyn range, however, north of Maentwrog Mr. Williams has found *Didymograptus Murchisoni* and *Climacograptus Scharenbergi* in slates above the highest Arenig agglomerate, and again at Tiddyn Dicwm near Tremadoc graptolites have been found and identified by Professor Lapworth as *Dicranograptus ramosus*, *Diplograptus tricornis*, *Climacograptus Scharenbergi*, *C. bicornis*, all Llandeilo species.

East of the Arans, Selwyn found 5500 feet of strata between the upper ash and the Bala limestone; some 2000 feet of this may be Llandeilo, but east of Moel Dhu, Jukes found only 4000 feet between the same limits; some of the beds therefore thin to the northward.

Undoubted Llandeilo beds emerge again in the centre of the Berwyn anticline, and near Llanrhyader the lowest beds are limestones several hundred feet thick, containing *Asaphus tyrannus*, *Trinucleus favus*, *Calymene cambrensis*, *Orthis turgida*, and *Orthis verpertilio*. The total thickness of the series in this inlier is estimated by Ramsay at 4500 feet, and they include some beds of felstone and felspathic ash which cannot be on the horizon of the Arenig rocks, as Ramsay supposes, but are doubtless comparable with those of the Shelve district.

Bala Series.—The strata of this series occupy a large area in North Wales; they fill the centre of the Lleyn and Snowdon syncline, and form a continuous tract ranging from Conway in Denbigh southwards by Bala and Dinas Mowddwy (see map, Fig. 14). They also form the mass of the Berwyn Mountains in South Denbigh, rising up from beneath the Silurian in a huge periclinal dome, and enclosing the Llandeilo of Llanrhyader.

As stated above, the base of the Bala series has not yet been definitely determined in North Wales, and consequently the thickness of the series is uncertain. In Merioneth, near Bala and Dinas Mowddwy, there are from 2000 to 3000 feet of gray sandy shales with interstratified beds of fine grained sandstone, and these, with the Bala limestone, which overlies them, are generally considered

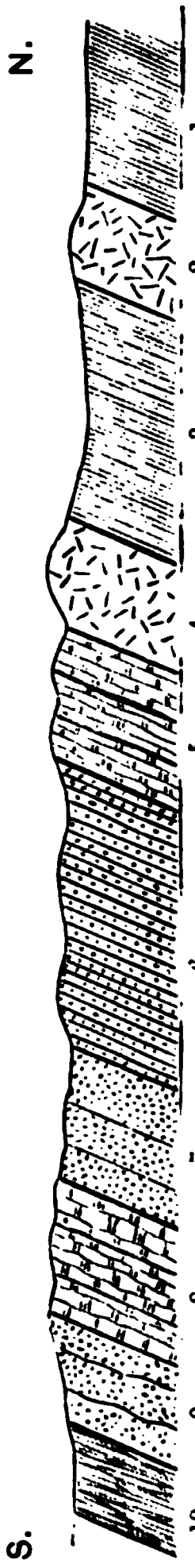

Fig. 30.—SECTION THROUGH THE BALA LIMESTONE NEAR GELLIGRIN, SOUTH OF BALA LAKE (Ruddy).

4. Volcanic ash.
3. Shales with *Orthis*.
2. Calcareous ash.
1. Fossiliferous shales.

7. Coarse sand like No. 9.
6. Sandy shales, trilobites.
5. Sandy limestone, brachiopods.

10. Shales with *Leptæna sericea*.
9. Coarse sand, many fossils.
8. Crystalline limestone.

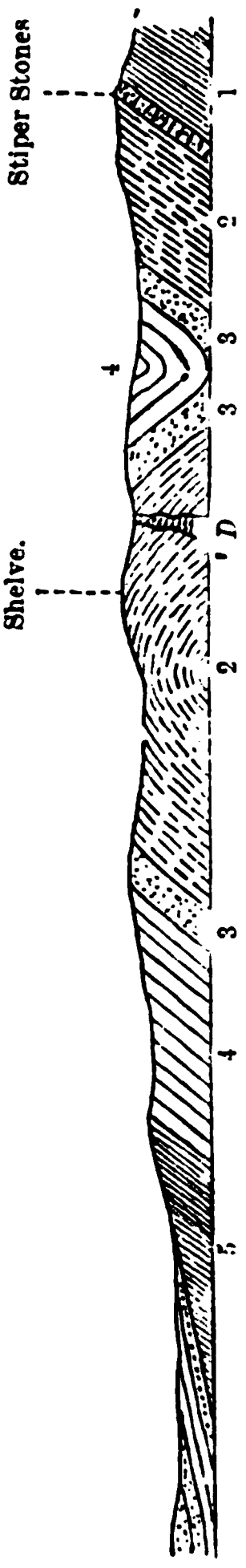

Fig. 31.—SECTION ACROSS THE DISTRICT OF SHELVE (after G. H. Morton). Distance about 8 miles.

4. Llandeilo series.
3. Volcanic ash.
2. Arenig series.
1. Shineton shales.
D. Dyke of igneous rock.

6. Silurian rocks.
5. Bala series.

as forming a Lower Bala group. In the middle of these Lower Bala shales there are some beds of volcanic ash, the chief of which is 15 feet thick, and its outcrop forms a feature which can be followed for many miles. There are other beds of ash just below the Bala limestone.

Above this limestone there is some 1500 feet of sandy shale, and then another thin band of limestone and calcareous shale, which is known as the Hirnant limestone. These beds are known as the Upper Bala group, and there may be still higher beds belonging to the series, but if so they are concealed by the overstep of the basal Silurian grits.

From recent accounts it would appear that the Bala limestone is not a single bed or set of beds varying in thickness from 3 to 50 feet and always containing the same set of fossils. On the contrary, there is reason to think that the beds which have hitherto been grouped as Bala limestone include two distinct horizons or zones, that the name Bala limestone should be restricted to the lower of these zones, and that the upper is the Rhiwlas limestone, which was formerly exposed at Rhiwlas, north of Bala, and is the equivalent of the Sholeshook limestone in Pembrokeshire.

Even the main mass of the Bala limestone is often split up into several beds by the intercalation of calcareous sandstone or shale, as at Gellygrin, to the south of Bala Lake, as described by Mr. T. Ruddy. Here there is a lower limestone, 12 feet thick and containing many fossils, succeeded by sandy shales with many of the characteristic Bala trilobites, and some feet higher a hard, massive, crystalline limestone 18 or 20 feet thick, the whole group of beds (five to eight) being about 50 feet thick.

The characteristic fossils of the Bala limestone are *Trinucleus concentricus*, *Asaphus Powisi*, *Phacops apiculatus*, *Homalonotus bisulcatus*, *Orthis vespertilio*, *O. spiriferoides*, and *O. biforata*. Those of the Rhiwlas limestone are *Cyrtoceras sonax*, *Orthoceras vagans*, *Trinucleus seticornis*, *Ampyx tumidus*, *Encrinurus sexcostatus*, *Staurocephalus clavifrons*, *Phacops Brongniarti*, *Leptæna tenuicincta*, *Sphæronites Litchi*, *Echinosphæra aurantium*, *Hemicosmites rugatus* and other cystid echinoderms.

The most characteristic fossils of the Hirnant limestone and of the associated shales are species of *Orthis*, *O. hirnantensis*, *O. sagittifera*, *O. biforata*, with some bivalves such as *Arca edmondiiformis*. This limestone band is from 5 to 10 feet thick, and consists of concretionary pisolitic limestone and calcareous shale. From the above account it will be seen that the succession in the typical Bala district may be summarised as below :—

		Feet.
Upper Bala	Hirnant limestone	5 to 10
	Gray shales and shaly sandstones	1500
	Rhiwlas limestone	10 to 20
Lower Bala	Bala limestone	10 to 50
	Gray slates and thin sandstones	1400
	Main ash bed	15
	Gray slates and thin sandstones	1300
		Over 4000

The limestones thicken eastward, and in the Berwyn Mountains they have a combined thickness of from 200 to 300 feet. The succession here has been described by Mr. D. C. Davies,[5] from whose account it would seem that the greater part of this mass belongs to the Bala limestone, but that at the top there is a remarkable set of beds consisting of calcareous shales and thin limestones with a bed of phosphatic nodules about a foot thick. These top beds seem to correspond to the Rhiwlas limestone, and contain *Echinosphæra*, *Caryocystis*, and other echinoderms, with *Illænus Davisi*, *Cyrtoceras arcuatum*, *C. sonax*, and *Orthoceras* of several species.

To the north and north-west of the Bala district the limestones appear to thin out, the Bala limestone containing much volcanic ash and passing into a nodular calcareous tuff. In the Snowdon range thick masses of felspathic lava and tuff are interstratified with the Lower Bala shales, and greatly increase the thickness of that group; one of the tuffs on the top of Snowdon is believed to be the equivalent of the Bala limestone, and the same bed has been traced northward to Conway.

The railway cutting west of Conway is a notable locality as being the only place in North Wales where recognisable graptolites of Bala age have yet been found. Among them Professor Lapworth identified *Dicranograptus Clingani*, *Diplograptus foliaceus*, *Climacograptus bicornis*, and *Idiograptus margaritatus*. Some other species from Conway are mentioned in Ramsay's memoir on North Wales (1881), p. 398.

3. *Shropshire*

The Ordovician rocks of South Shropshire are a continuation of those of Wales, and are brought up by the broad anticlinal flexure of which the Longmynd may be regarded as the central axis (see Fig. 3). They occur on both sides of the Longmynd district, but the lower part of the system is only found on the western side (in the Shelve and Corndon area), being absent on the eastern side (Caradoc area), where the Bala beds are brought

into apposition with the Shineton shales either by faulting or by overlap.

Arenig Series.—The base of this division consists of a hard siliceous grit or quartzite forming the ridge called the Stiper Stones; above this are gray and green flagstones with interbedded shales, in which Professor Lapworth has found *Ogygia Selwyni*, *Tetragraptus bryonoides* with species of *Phyllograptus* and *Trigonograptus* marking them as Lower Arenig. They are succeeded by black shales containing species of *Ogygia* and *Placoparia*, with *Didymograptus patulus* and *D. Nicholsoni*. The highest member of the series is a set of contemporaneous volcanic tuffs and shales, evidently deposited on the sea-floor, and probably ejected from the great Arenig volcanoes of North Wales. The total thickness is about 3000 feet.

Llandeilo Flags.—At the base of this series are the Weston Beds, consisting of shales with two massive beds of volcanic grit (felspathic); these are succeeded by shales and flags containing *Didymograptus Murchisoni*, overlain near Middleton Church and Meadowtown by flags and limestones containing many fossils, such as *Asaphus tyrannus*, *Ogygia Buchi*, and *Trinucleus Lloydi*. The highest beds are black mudstones yielding graptolites, among which are *Cœnograptus gracilis* and *Dicellograptus sextans*. The total thickness is uncertain, but may be from 3000 to 4000 feet.

Bala and Caradoc Series.—Continuing the above succession in the Shelve district the Bala beds are well exposed in the Spy Wood section. At the base are the Spy Wood grits and flags passing up into the Aldress shales; these beds yield *Trinucleus concentricus*, *Orthis calligramma*, *Diplograptus tunicatus*, *Climacograptus bicornis*, and other fossils. Above comes the Marrington group, a set of gray and black shales with interstratified beds of andesitic ashes and breccias or agglomerates; the highest shales are overlain unconformably by the Silurian (Upper Llandovery beds).

On the eastern side of the Longmynd the succession in the Caradoc district was first worked out by Murchison and formed the type of his "Caradoc sandstone." This, however, was subsequently proved to be only a local facies of the Bala series. The succession as corrected by Messrs. Callaway and Lapworth is as follows:—

Llandovery beds (unconformable)—

Caradoc sandstone, ? 4000 feet	*Trinucleus* shales.
	Acton shales and limestone.
	Cheney Longville flags.
	Harnage shales.
	Hoar Edge grits and sandy limestone.

All these beds contain fossils, and the Acton beds have yielded *Lichas laxatus*, *Ampyx*, *Orthis Actoniæ*, *O. flabellulum*, and many corals. It is quite possible that they represent the Bala limestone. The highest or Hirnant beds are concealed by the overstep of the Silurian.

4. *The North of England*

Ordovician rocks occupy a large area in the Lake District, which was the scene of Professor Sedgwick's earliest work on the rocks of this system (1832-36). All the mountainous region lying north-west of a line drawn from the estuary of the Duddon by Hawkshead and Ambleside to the valley of the Lowther Beck consists essentially of Ordovician rocks (see the map, Fig. 32, and section, Fig. 33).

They are also found in a long narrow inlier, known as the Cross Fell inlier, in the north-east of Westmoreland, bounded on the one side by Carboniferous limestone, and on the other by New Red Sandstone.

The Ordovician rocks of this area are divisible into three series, which are roughly equivalent to those of Wales and Shropshire.

Upper Skiddaw Slates.—It was stated on p. 87 that only the upper part of the formation at present known as the Skiddaw slates is of Ordovician age. The basement beds of this upper portion are certain beds of grit which are called the Watch Hill grits in a recent memoir of the Geological Survey.[6] The beds above this horizon are termed the Upper Skiddaw slates, and have yielded both graptolites and trilobites of Arenig species. They have been divided into several stages by Mr. J. E. Marr,[7] and his divisions are accepted by the Survey. In descending order they are as follows:—

3. Ellergill beds, with *Trigonograptus ensiformis*, *Glossograptus armatus*, *Diplograptus dentatus*, and *Cryptograptus antennarius*.
2. *Tetragraptus* beds, with *Tetragraptus bryonoides*, *T. quadribranchiatus*, *Phyllograptus typus*, and *Didymograptus gibberulus*.
1. *Dichograptus* beds, with *Dichograptus 8-brachiatus*, *Loganograptus Logani*, and *Temnograptus multiplex*.

The whole series is much folded and plicated, so that it is difficult to form any estimate of its thickness; probably it is not more than 3000 to 4000 feet, though older writers gave a greater thickness.

The Ellergill beds occupy a high position in the series, and their typical exposure is at Ellergill in the Cross Fell inlier, to

the east of the Lake District, but they occur also near Threlkald and Troutbeck, east of Keswick.

Borrowdale Series (Llandeilo-Bala).—The Skiddaw slates are succeeded by a great mass of volcanic rocks, andesitic and rhyolitic lavas, and associated ash beds, the total thickness of which is believed to be about 12,000 feet. In the Cross Fell inlier their lower parts are interstratified with dark slates, which have yielded *Didymograptus Murchisoni*, and *Diplograptus dentatus*, and these have been termed the Milburn beds. Similar beds have also been found near Ulleswater and other places. The highest portion of the volcanic series, however, may be of Bala age, for in the Cross Fell inlier and overlying the rhyolite of Roman Fell there are some calcareous shales, limestones, and ash beds which are of Lower Bala age, and appear to be older than the Coniston limestone. They are termed the "*corona* series" by Mr. Marr, and contain *Trematis corona*, *Lingula tenuigranulata*, *Orthis testudinaria*, and other fossils. The limestones consist largely of the tests of the small Crustacea called *Beyrichia*.

Coniston Limestone Series.—Above the "corona beds" just mentioned in the Cross Fell inlier come the Dufton shales and the Keisley limestone, which have a combined thickness of about 200 feet, but in the Lake District these seem to be represented by the Coniston limestone, which is about 100 feet thick and contains most of the fossils of the Welsh Bala limestone. Moreover, the close similarity of the two series is increased by the fact that the topmost beds of this limestone contain the special fauna of the Rhiwlas and Sholeshook limestone, *Staurocephalus globiceps*, *Caryocystites Davisi*, *Holopea concinna*, and *Orthoceras vagans*.

The limestone is succeeded by the dark blue and gray Ashgill shales, which have yielded *Phacops apiculatus*, *Trinucleus seticornis*, *Strophomena siluriana*, and *Orthis protensa*, and correspond to the Upper Bala shales of North Wales.[8] These Ashgill shales are not more than 50 feet thick, so that the development of the Bala sediments in the Lake District is small, but, as above stated, this is doubtless because the lower portion is replaced by beds of volcanic origin.

In a later paper[9] Mr. Marr gives the following classification of the Bala series in Cumberland, Westmoreland, and Yorkshire, with a tabular view of the variations at different places:—

			Feet.
Coniston Limestone Series	Ashgill group	Ashgill shales	50
		Staurocephalus limestone	5
	Sleddale group	Applethwaite limestone	100
		Conglomerate	10
		Stile End beds	50
	Roman Fell group	Corona beds	100

Fig. 82.—MAP OF CUMBERLAND AND WESTMORLAND.

Fig. 38.—GENERALISED SECTION ACROSS THE LAKE DISTRICT FROM THE SOLWAY TO KIRBY LONSDALE. Drawn by Mr. J. G. Goodchild.
Distance about 60 miles.

n. Penrith sandstone.
m. Upper Carboniferous.
k. Carboniferous limestone.
g. Ludlow series.
f. Wenlock series.
e. Stockdale shales.
d. Coniston limestone.
c. Borrowdale series.
b. Skiddaw slates.
a. Plutonic rocks (granite, etc.).

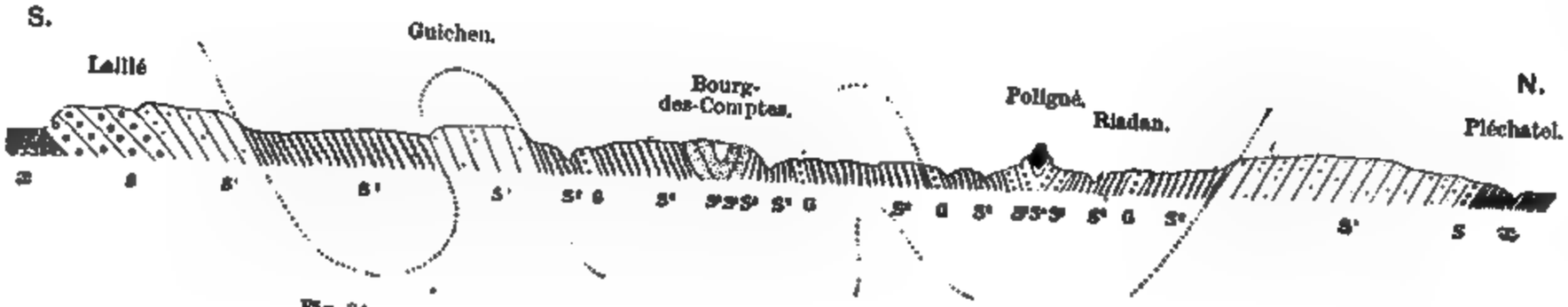

Fig. 34.—SECTION ALONG THE VALLEY OF THE VILAINE NEAR POLIGNÉ IN BRITTANY (Barrois).

S4. Silurian.
S3. Slates of Riadan.
G. Sandstone of Chatellier.
S2. Slates of Sion (Llandeilo).
S1. Armorican sandstone.
S. Cambrian sandstones and slates.
x. Brioverian.

Mr. Goodchild believes that there is a still lower horizon of *corona beds*, for below Mr. Marr's *corona* beds there is a great thickness of rhyolitic lavas and ashes which are divisible into two groups—the Dufton and Yarlside rhyolites and the Helton Moor beds, and below these are shales about 500 feet thick, which also contain *Trematis corona*. According to him, therefore, the thickness of Bala rocks in the Cross Fell inlier is very much greater, but this requires confirmation (see *Geol. Mag.* 3, ix. p. 295).

Mr. Goodchild believes also that there is a local unconformity which increases in extent toward the north, so that this Bala series rests in different places on different portions of the underlying Borrowdale series, this unconformable relation being a result of the earth-movements accompanying the local volcanic outbursts.

5. *South Scotland*

The southern uplands of Scotland are largely composed of Ordovician and Silurian rocks folded together into a number of anticlinal and synclinal folds, each fold having its subsidiary plications, so that the country has a complicated structure, and can only be successfully mapped by careful attention to fossils. The older views about this region were mistaken because the fossils were not sufficiently studied, and because it was supposed that graptolites were characteristic of Llandeilo beds and did not occur outside their limits. The true structure and succession of strata in this region was first established by Professor Lapworth, whose researches on the Girvan and Moffat districts are embodied in two detailed papers,[10] and who afterwards summed up the structure of the whole region in another one,[11] to which the student should refer. The sections, Figs. 35 and 36, are taken from these papers.

The special interest of this region is that it presents us with two very different facies of sedimentation, which, however, can be traced through changing intermediate types from the one area to the other. In Ayrshire (Girvan, etc.) the Ordovician has the ordinary facies of a formation accumulated at no great distance from a continental coast-line, consisting as it does of a considerable thickness of conglomerates, sandstones, shales, with at least one bed of limestone. The other type, found in Dumfries and Wigtownshire, is one that must have been formed in much deeper water, for there the whole system is condensed into a small thickness of dark graptoliferous mudstones, shales, and chert beds. The base of it is not exposed, but the total thickness from the summit of the Bala series down to the base of the Arenig chert beds is only about 185 feet, as compared with a thickness of 3500 feet in Girvan.

Fig. 35.—SECTION ACROSS LANARKSHIRE AND DUMFRIESSHIRE FROM CAIRNTABLE TO LANGHOLM (after Professor Lapworth). Distance about 50 miles.

8. Lower Carboniferous.
7. Old Red Sandstone.
6. Riccarton group.
5. Gala group.
4. Birkhill shale.
3. Hartfell shales.
2. Glenkiln shales.
1. Ballantrae group (Arenig).

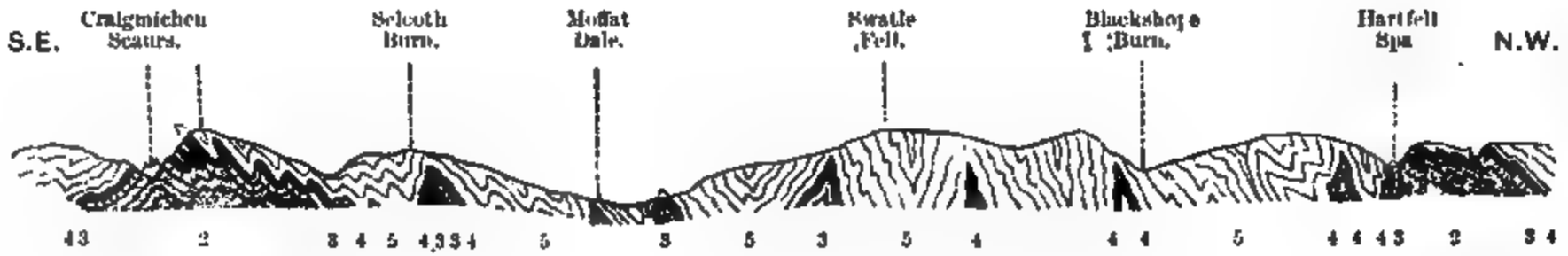

Fig. 36.—SECTION THROUGH THE MOFFAT DISTRICT (from Professor Lapworth's paper in the *Quart. Journ. Geol. Soc.*). Distance about 6 miles. References the same as to Fig. 35.

The following is a tabular account of the succession in the two typical areas :—

	Girvan District.	Moffat District.
Ardmillan Series, 2600 feet (Bala).	DRUMMUCK BEDS, 400 feet— *b.* Shales with *Staurocephalus.* *a.* Shales with *Trinucleus seticornis.* SHALLOCH FLAGS, 800 feet— Flagstones and shales with *Dicellograptus truncatus.* WHITEHOUSE BEDS, 300 feet— *b.* Beds with *Dicellogr. complanatus.* *a.* Beds with *Leptogr. flaccidus,* etc. ARDWELL FLAGS, 1000 feet— *b.* Beds with *Dicrano. ramosus* and *Diplograptus rugosus.* *a.* Beds with *Crypto. tricornis* and *Diplograptus foliaceus.* BALCLATCHIE BEDS, 100 feet— Grits and sandstones with *Climacograptus bicornis* and *Cryptogr. tricornis.* Shales with *Glossograptus Hincksi.*	HARTFELL SHALES, 100 feet— 6. Zone of *Dicellograptus anceps* and *D. truncatus.* 5. Barren mudstones. 4. Zone of *Dicello. complanatus.* 3. Zone of *Pleurograptus linearis* and *Lepto. flaccidus.* 2. Zone of *Dicranograptus Clingani* and *D. ramosus.* 1. Zone of *Climacogr. Wilsoni* and *Cryptogr. tricornis.*
Barr Series, 800 feet.	BENAN CONGLOMERATE, 500 feet. STINCHAR GROUP, 100 feet— *b.* Shales with *Didymogr. superstes* and *Dicellogr. sextans.* *a.* Limestones with *Maclurea Logani.* KIRKLAND BEDS, 200 feet— Sandstones and conglomerates with *Orthis confinis.* Unconformity here.	GLENKILN SHALES, 21 feet— Black shales with *Dicranograptus ziczac* and *Climacograp. calatus.* Yellow mudstones. Black shales with *Cœnograptus gracilis* and *Didymogr. superstes.* RADIOLARIAN CHERT BEDS (upper part) ? 23 feet— Yellow and gray shales with bands of chert.
Arenig Series, 1500 feet.	RADIOLARIAN CHERTS, red and gray cherts, mudstones, and volcanic tuffs, about 70 feet— Black shales of Bennane Head with *Tetragraptus bryonoides,* 4 feet. VOLCANIC ROCKS, lavas and tuffs with thin shales containing *Tetr. bryonoides,* 1500 feet seen.	RADIOLARIAN CHERT BEDS (lower part) - Mudstones with chert beds, ? 30 feet. Volcanic tuffs at Trowdale, 150 feet. Base not seen.

It is a curious fact that no fossiliferous beds of Lower Llandeilo age have been found in either region, and that *Didymograptus Murchisoni* has not yet been found in Scotland. The Kirkland conglomerate rests unconformably on the Arenig series, and the fossils of the Stinchar group are of Upper Llandeilo age. Messrs. Peach and Horne suggest that in the Moffat district the Lower Llandeilo is represented by the upper part of the Radiolarian chert beds. Fig. 37 represents the succession seen in Trowdale Glen (Urrdale), according to these observers, and is copied from their memoir on the Southern Uplands.

In the **Barr Series** the Stinchar limestone is an interesting horizon, for many of its fossils are not found anywhere in England, but occur in the Trenton limestone of North America; such are *Maclurea Logani*, *M. magna*, *Murchisonia angustata*, the sponge-

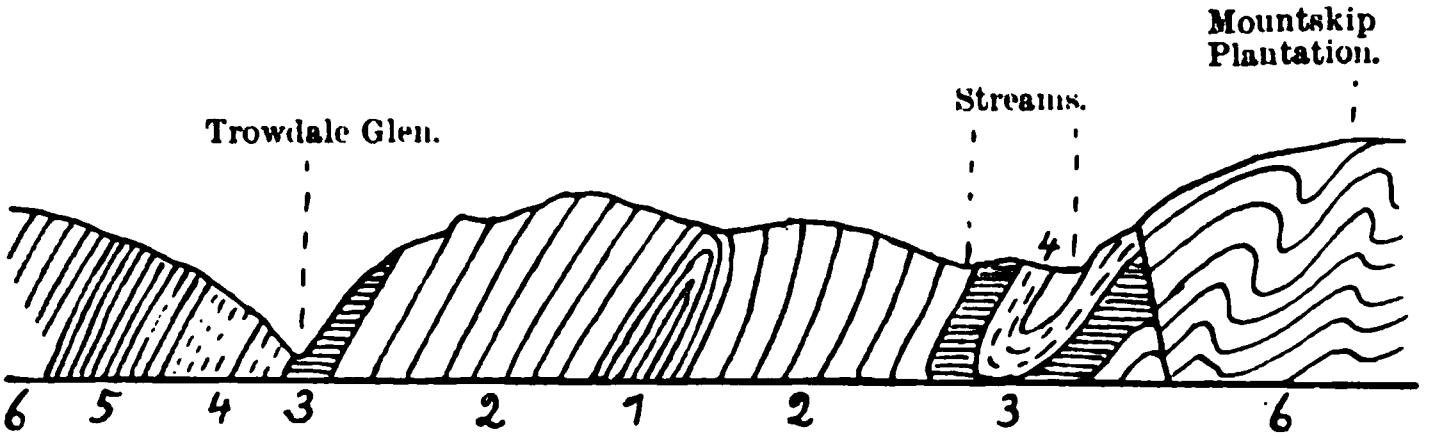

Fig. 37.—SECTION THROUGH TROWDALE IN THE VALLEY OF THE URR (KIRKCUDBRIGHT).

6. Gala beds.
5. Birkhill shales.
4. Hartfell shales.
3. Glenkiln shales.
2. Radiolarian chert beds.
1. Volcanic tuffs (Arenig).

like coral *Tetradium*, and *Saccaminu Carteri*; there are also many corals (*Lyopora favosa*, etc.) and brachiopods, with *Lichas sexcostatus* (?), *Illænus latus*, *I. Bowmanni*, and *Calymene Blumenbachi*, most of which range from Upper Llandeilo to Bala beds.

The Balclatchie beds are included in the Barr series by Professor Lapworth, but he speaks of them as forming a transitional band or zone, and many of the graptolites range into the Hartfell shales. Messrs. Peach and Horne place these beds in the Ardmillan or Bala series, but leave the Benan conglomerate in the Barr series. It is possible that the plane of division should be drawn between the Balclatchie shales and the overlying grits.

The Ardmillan Series, which is the equivalent of the Welsh Bala beds, consists of a great thickness of alternating flagstones, sandstones, mudstones, and shales. It is interesting to note that near the top of the highest (Drummuck) group there is a thin bed of grit which has yielded *Staurocephalus globiceps*, *Trinucleus Bucklandi*, a species of *Palæaster* and other fossils, associated with shales

containing *Dicellograptus anceps* and *Diplograptus truncatus.* The graptolites show that these beds are equivalent to the highest part of the Hartfell shale, but there are no limestones comparable with those of Bala and Coniston.

Beds of the Moffat type, dark shales, and mudstones have been traced all across Southern Scotland from the Lammermuir Hills through the northern parts of Selkirk and Dumfries, and the central parts of Kirkcudbright and Wigtown. Beds of an intermediate type form a broad belt to the north of this, varying from 5 to 15 miles in width from the Moorfoot Hills to the northern part of Wigtown.

6. *Ireland*

More zonal work is required in the Ordovician districts of Ireland before anything like a complete account of them can be given. They are known to occur in many places from Wexford and Waterford in the south-east to Mayo and Galway in the north-west, and it is specially noteworthy that in proceeding from the former to the latter region we find the beds exhibiting three successive different facies similar to those existing in Great Britain, which may be termed the Welsh, Cumbrian, and Scottish facies. It is only recently, however, that the existence of Arenig beds in Ireland has been ascertained.

Southern Facies.—In the county of Wexford there is a great thickness of Ordovician rocks, estimated at from 5000 to 6000 feet, but though it probably includes Arenig beds, these have not yet been identified where the base is best seen, *i.e.* in the extreme south-east, where beds of purple conglomerate and sandstone rest unconformably on Pre-Cambrian gneiss and schist. The sandstones are overlain by black slates with graptolites partly at any rate of Llandeilo age, and these are succeeded by some 3000 feet of gray shales containing Bala fossils and interstratified with beds of volcanic ash and flows of felspathic lava like those of North Wales.

In North Wexford and Wicklow, beds of Arenig age come in below the black slates; these consist of striped slates with thin layers or seams of grit, and are known as the Ribband series. They have recently been mapped over a large area by Messrs. Egan and M'Henry,[12] and fossils have been found in them near Arklow, Courtown, and Kiltrea; these included species of *Tetragraptus*, *Phyllograptus*, and *Didymograptus*, *Caryocaris Wrighti* and a *Bryograptus* like *Kjerulfi*. The occurrence of the last would seem to indicate that even Tremadoc rocks are present.

Above the Ribband series are black slates which have yielded graptolites of Llandeilo age, including *Dicranograptus ramosus*, *D. ziczac*, *Leptograptus flaccidus*, *Diplograptus mucronatus*, and *Cœnograptus gracilis*. These beds are succeeded by limestones of Bala age which have yielded many fossils.

Central Facies.—At Portraine on the Dublin coast there is one of the finest sections of the Coniston limestone and its associated rocks to be found in the British Islands. Ash beds and lavas comparable to the Borrowdale beds are succeeded by green shales with calcareous nodules, which pass by gradations into a calcareous group containing massive limestones, with fossils of the Coniston limestone. This locality is exactly on the line of strike of the Lake District exposures, and the same line prolonged carries us south-west into Kildare, where the range of hills called the Chair of Kildare consists of the same rocks, including limestone, with abundance of fossils.

Northern Facies.—In the counties Down, Armagh, Monaghan, and Cavan the thickness of the Ordovician beds is reduced to a band of black shales and mudstones exactly resembling those of Moffat and the southern Scottish belt. Many years ago, from exposures south of Belfast Lough, Mr. Swanston obtained all the characteristic graptolites of the Glenkiln and Hartfell shales. There are also some narrow inlying anticlinal exposures among the neighbouring Silurians, and in one of these near Slane (County Meath) Mr. M'Henry has found some layers of banded Radiolarian chert and dark shales yielding Lower Llandeilo or Arenig graptolites.[13]

It is probable that this facies is prolonged south-westward beneath the Carboniferous rocks, for in Clare and Tipperary there are inliers of the older Palæozoics, chiefly Silurian, but including some tracts of Ordovician, and these have yielded graptolites of Glenkiln and Hartfell species.[14]

Still farther to the north-west, in Tyrone (Pomeroy), Mayo, and Galway, there is a series of Ordovician rocks which more resemble those of the Girvan area. At the base are black shales with bands of red and black chert, and in close proximity is a volcanic series which includes a thick band of limestone containing Bala fossils. Finally, in the Mweelrea Mountains rocks of Llandeilo age are overlain by a series of grits and conglomerates, part of which have recently been proved (*op. cit.* p. 50) to be of Bala age, and this change from a deep water to a shallow water facies is significant of the proximity of land. These Bala beds extend for some distance northward toward Clew Bay, and may once have covered a large part of Mayo.

Continental Equivalents

Scandinavia

Ordovician rocks occupy considerable areas in the southern parts of Norway and Sweden, and in Scania the Cambrian sequence given on p. 91 is conformably succeeded by the following series of beds with a total thickness of only 300 to 400 feet, but including representatives of the whole system. In descending order the succession is :—

Bala	13.	Blue flags with *Phacops eucentra.*
	12.	Green shales and calcareous grits with *Sphærexochus* and *Staurocephalus clavifrons.*
	11.	Red and gray shales with *Trinucleus seticornis* and *Dicellograptus anceps.*
	10.	Shales with *Climacograptus rugosus.*
	9.	,, ,, *Dicranograptus Clingani.*
	8.	,, ,, *Climacograptus Scharenbergi.*
Llandeilo	7.	Shales with *Cœnograptus gracilis.*
	6.	,, ,, *Diplograptus putillus.*
	5.	,, ,, *Glossograptus Hincksi.*
	4.	,, ,, *Didymograptus geminus* (=*Murchisoni*).
Arenig	3.	Shales with *Phyllograptus typus.*
	2.	The Orthoceras limestone.
	1.	Tetragraptus shales (*T. serra*, etc.).

This succession is based on the work of Linnarsson, modified by the more recent explorations of Tullberg[15] and Marr.[16] The Tetragraptus shales rest on the Ceratopyge limestone (see p. 91). The Orthoceras limestone abounds in Orthoceratites, especially those of the subgenus *Endoceras*, together with many trilobites and other fossils. These beds, with the overlying Phyllograptus shales, correspond to our Arenig, but are only 150 feet thick.

The succession of zones is bracketed in the above table to show their correlation with the British groups, but the Swedish grouping is different. No. 4 is probably the equivalent of our Lower Llandeilo, and 5, 6, 7 correspond to the Glenkiln shales, but in other parts of Scandinavia some of these shales are replaced by limestones with *Chasmops* and *Beyrichia*. Nos. 8, 9, 10, 11 correspond with the chief part of the Hartfell shales, while 12 and 13 are evidently the equivalents of the Ashgill shales and the Upper Bala beds of Wales.

In Russia there is a similar series, but more calcareous, of about the same thickness.

North-Western France

The only other extra-British region of which any detail need be given is that of Normandy and Brittany. In Normandy the Ordovician is divisible into four groups, none of which has any great thickness, and the succession near May-sur-Orne is as follows :—

	Feet.
4. Green slates	About 200
3. Grès de May (pink and gray sandstones) with *Calymene Tristani*, *Homalonotus Vicaryi*, *Orthis budleighensis*.	,, 500
2. Slates with *Calymene Tristani*, *Dalmanites Philippsi*	,, 200
1. Grès Armoricain, a white sandstone	,, 200

In Brittany the Ordovician has a greater thickness and comprises the following groups (see section, Fig. 34) :—

4. Limestone of Rozan, with *Orthis actoniæ*.
3. Sandstones and shales with *Calymene Tristani*, *Homalonotus Aragoi*, *Trinucleus Bureaui*, and *Acaste incerta*.
2. Slates of Angers and of Sion with *Calymene Tristani*, *Dalmanites Phillipsi*, and species of *Placoparia*, *Ogygia*, and *Asaphus*.
1. Grès Armoricain with *Asaphus armoricanus*, *Lingula Lesueri*, and species of *Redonia* and *Ctenodonta*.

The Armorican sandstone is of considerable thickness (500 to 1000 feet), making with the underlying grits and conglomerates (see p. 95) a mass of arenaceous rock from 1600 to 2500 feet thick. It contains very few fossils, but may be regarded as equivalent to part of our Arenig series.

The slates of Angers are divisible into two parts, which are in some places separated by a sandstone. The lower slates of Sion contain *Didymograptus Murchisoni* and *D. enodus*, which correlate them with our Lower Llandeilo. The upper or Riadan slates yield *Trinucleus pongerardi*, *Diplograptus foliaceus*, and *D. angustifolius*, and represent the Upper Llandeilo.

The overlying sandstones of St. Germain-sur-Ille, of Kermeur, and of Redon contain species of *Diplograptus* and of *Trinucleus*, and with the Rozan limestone represent the Bala series.

It may be mentioned that in the south of France (Languedoc), there is a similar sequence, and that the lower part of the Armorican sandstone is replaced by shales with calcareous nodules which have a thickness of nearly 500 feet, and have yielded many fossils, including *Tetragraptus serra* and *T. quadribrachiatus*, species which establish their Lower Arenig age and make it fairly certain that the Armorican sandstone is of that age.

Ordovician Volcanoes

Rocks of volcanic origin play a prominent part in the records of this system. As the ashes and lavas are interstratified with fossiliferous marine strata, it is probable that the eruptions took place either from submarine vents or from groups of volcanic islands, such as occur in the Pacific Ocean of the present day.

In Wales these outbursts commenced in Arenig times, that series containing thick lenticular masses of felspathic lava and ash (see Fig. 14, p. 77). These interbedded masses are thickest in Cader Idris and Aran Mowddwy, but thin away rapidly both to the north and south of this district. At Aran Mowddwy their united thickness amounts to over 5000 feet, but this is reduced at the northern end of the Aran range to 2350 feet, and in the Arenig Mountains to 1050. The associated agglomerates are traceable westward as far as the Moelwyn range, but die away rapidly beyond that.

This great mass of volcanic material is mainly disposed in three separate bands: (1) a lower set of ashes and conglomerates with a maximum thickness of 3300 feet; (2) a middle group of "felstones" and "porphyries," the details of which have not been worked out; (3) an upper set of fragmental deposits like No. 1, but not exceeding 800 feet.

Eruptive materials of this age occur also in the Berwyn Mountains to the eastward, and again in the Shelve district of Shropshire, where volcanic grits occur also in the Llandeilo group.

The southern part of Scotland was another great centre of volcanic eruption in Arenig time, rocks of volcanic origin having been traced along a belt of at least 100 miles in length. They are included in the Ballantrae group of Professor Lapworth, and are well exposed on the coast of Ayrshire near that place. The lavas are chiefly diabases, some dark green, compact, and fine-grained, others purple and markedly porphyritic with large phenocrysts of plagioclase, all consisting essentially of plagioclas felspar, augite, and iron ores. Associated with these lava-flows are beds and bosses of agglomerate and some fine tuffs. Some of the actual vents from which these materials were ejected seem to have lain in the south of Ayrshire, for some of the agglomerates there contain blocks of porphyry up to a yard in diameter, and the evidences of volcanic action tend to become less as the beds are followed to the north-east.[17]

A third great centre of volcanic energy during this period is found in the Lake District. Here they form what is known as the

Borrowdale volcanic series, the lowest lavas occurring in the highest part of the Skiddaw (Arenig) slates, and the highest being of Bala age, but the mass of the series evidently belonging to the intervening Llandeilo epoch (see p. 115). These volcanic rocks consist of andesitic lavas, ashes, and agglomerates of green or purple colours, which were termed the "green slates and porphyries" by Professor Sedgwick. The cleavage which traverses the district converts some of the finer ash beds into regular slates, as seen in the quarries at Dale Head. A similar series is found in the Isle of Man.

In Ireland, felstones, gabbros, tuffs, and agglomerates occur in the Llandeilo series of Wicklow and Wexford ; porphyritic felstones and ash beds of the Borrowdale type appear near Portraine, Co. Dublin.

In North Wales there are no eruptive rocks of Llandeilo age, but after a period of repose volcanic activity was renewed. The normal development of the Bala rocks has been described on p. 112, but north of Moel Siabod the series assumes a very different character from the interpolation of numerous beds of felstone and volcanic ash. "These range northward to Conway, and from thence south-westward along the higher Caernarvonshire mountains. Carnedd-Llewellyn, Carnedd-Dafydd, Y-Glyder-fach, Y-Glyder-fawr, Snowdon, and Moel-Hebog are the chief mountains in this the highest, wildest, and grandest part of North Wales ; and these consist in a great degree of true volcanic products, some of which are interbedded, and some of the intrusive masses may be the deep-seated centres of volcanic eruptions."[18] As shown in Fig. 27, the Snowdon range occupies the western side of a complicated synclinal flexure, which is continued throughout the promontory of Lleyn. The structure of the range is as follows : upon the Bala slates and grits lie three great beds of porphyritic felstone, which southward converge into one mass ; these are succeeded by beds of felspathic, sandy, and calcareous ash, some of which contain fossils, and are supposed to represent the Bala limestone ; the ash beds are capped here and there by the relics of another sheet of felspathic lava, which has been nearly all removed by subsequent erosion. The total thickness of these accumulations is over 3000 feet, being as follows :—

	Feet.
Columnar felstone	200
Ashy beds	1200
Porphyritic felstones	1700

Some of the Bala felstones have been studied by Professor Bonney, and others by Mr. Rutley, and prove to be devitrified rhyolites,

exhibiting fluxion structure under the microscope; some are spherulitic, and others have a peculiar nodular structure.

For further details respecting these and other volcanic rocks the reader is referred to Sir Archibald Geikie's work on this subject.

Geography of the British Region

From the facts mentioned in the preceding pages it would appear that the subsidence which began in the Cambrian period was continued during the formation of the Ordovician sediments over the greater part of the British region. But over a certain space in the sea which covered England there was an upward movement resulting in the appearance of land composed of Cambrian and Pre-Cambrian rocks.

The facts bearing on the existence of this land may be summarised as follows. The chain of evidence begins in Shropshire, where the complete Ordovician succession is found on the western side of the Longmynd, while on the eastern the Bala series only remains, resting unconformably (at Hope Bowdler) on the Pre-Cambrian rocks, and containing rock fragments derived from them. Hence we infer that the Arenig and Llandeilo beds thinned out against a coast-line between Shelve and Hope Bowdler, and that the land subsequently sank so as to allow the Bala beds to overlap the lower shales and rest on the Cambrian and Uriconian rocks.

The specially arenaceous character of the Caradoc sandstone indicates that it was also found in proximity to a coast-line, and when the Cambrian again emerges in the Lickey Hills (Worcestershire) we find it succeeded by the Silurian without the intervention of any Ordovician, so that this district may have been land throughout the whole of the period.

How far the Ordovician land thus indicated extended to the eastward we cannot say, for we do not yet know whether any Ordovician rocks ever existed beneath the more eastern of the Midland counties or not. In North Warwickshire, where Cambrian rocks once more come to the surface, and again in Leicestershire, where still older rocks occur, they are covered by beds of Carboniferous and Triassic age, so that, for aught we know to the contrary, both Ordovician and Silurian may have existed in those counties and may have been destroyed during the great continental period of the Old Red Sandstone. At the same time the structure of Warwick and Leicester is so similar to that of Stafford and Worcester that it is very probable that all these counties have had

the same physical history, and arguing on this basis we may assume that Silurian strata did originally extend over all of them, but that the Ordovician did not.

None of the deep borings hitherto made in the east of England have touched rocks containing Ordovician fossils, though the rocks reached at Culford and Harwich may belong to this system, and beds of Llandeilo and Bala age come to the surface again in Belgium. At present, therefore, we have no clue to the eastern limits of the land above indicated, but it was probably an island.

Passing southwards from the Lickey to the Malvern Hills we find a similar absence of Ordovician in the latter, with Silurian resting directly on Cambrian, from which we may conclude that the Malvern area was included in the land tract, but how much farther it extended southwards is quite uncertain, as the base of the Silurian is not again exposed in Southern England till we reach Cornwall.

Ordovician rocks are believed to exist in the southern part of Cornwall, and are associated with other beds of Pre-Devonian age which are now known to occupy a broad belt of country from Truro and Tregony on the north to Meneage and Mounts Bay on the south, where they are faulted against the crystalline rocks of the Lizard peninsula. The succession of these beds has recently been worked out by Mr. J. B. Hill, and is given as follows: (1) Veryan beds; (2) Portscatho slates; (3) Falmouth slates; (4) Mylor series. They are intensely plicated and altered by pressure, and though the prevalent dip of the folds is to the south-east, the actual stratigraphical order may be in a reverse direction, and if this is the case the Veryan beds will be the oldest and the other groups may be of Silurian age.[19]

It is the Veryan beds that have yielded fossils which appear to be of Bala age, and they also include a massive conglomerate which is well exposed at Nare Head, south of the Helford River. This conglomerate contains rock-fragments of various kinds and sizes, including some large blocks; they are mostly subangular, but some are rolled, and Professor Bonney has inferred that land must have existed at no great distance from Nare Head at the time when this conglomerate or breccia was formed. Samples examined by him show that this land consisted largely of the following rocks: (1) granitoid gneiss like that of North-west Scotland; (2) fine-grained schists; (3) true slates or argillites; (4) grits and quartzites; (5) felsites and andesites.[20] Some of these rocks are not unlike those of the Lizard district, and it is very probable that this district formed part of the land from which the fragments were derived. The conclusion that such land lay to the south of the Meneage

district finds confirmation in the fact that the Falmouth slates become more and more arenaceous as they are traced to the south-west from Falmouth, and more argillaceous from that place northward.

It seems probable, therefore, that the land which furnished the material of the Nare Head conglomerate was a remnant of the land which appears to have existed in Cambrian times between Cornwall and Brittany (see p. 95). That portion of this land-area which entered into the structure of Brittany seems to have been submerged in Tremadoc and Arenig times, and toward the close of the Ordovician period it may have been reduced to the condition of an island.

Where then was the main coast-line of the period? In all probability it lay out in the Atlantic, its borders touching the extreme west and north-west of Ireland, and it may possibly have extended through the north-west of Scotland. The Bala conglomerates of the Mweelrea Mountains (County Mayo) thicken southwards and die away toward the north, and it is surmised that there was a considerable area of elevated land to the southward of those mountains, and that the Connemara district was a part of it, perhaps projecting eastward as a promontory. Another such tract may have extended through Donegal and Londonderry (as in Cambrian time), and there must have been land in the neighbourhood of Ayrshire in Llandeilo time to supply the materials of the great Kirkland and Benan conglomerates. The absence of the Lower Llandeilo in the Girvan district and the unconformity of the Kirkland conglomerate are facts which indicate the local upheaval of a portion of the area into land. This may have been an island or a temporary extension of the land which lay to the north-west.

There is good reason to believe that rocks of Arenig-Llandeilo occur along the border of the Scottish Highlands from Kincardine to Dumbartonshire, and more recently similar rocks have been found in the Isle of Arran. They consist of black shales (or schists), red and gray cherts, and various rocks of igneous origin, the whole resembling the Arenigs of Ayrshire, but no fossils have yet been found in them. If these rocks are Ordovician, a large part of Central Scotland must have been covered by the sea in Arenig times, though volcanic islands may have existed here and there.

The source of the sediments which constitute the Arenig series in the south of Scotland and the north of England is not yet apparent; indeed they and the Tremadoc slates seem to have been formed during the culmination of a long period of subsidence,

when the greater part of the British region was covered by sea, and when the deepest parts of this sea formed a trough extending from north-east to south-west through the south of Scotland and a large part of Ireland.

Those, however, who claim that the radiolarian cherts of this region are "oceanic deposits" jump to a very important conclusion from a very small amount of evidence. Only two reasons have been given for such an inference: (1) the existence of the Radiolaria, which at the present day form deposits on oceanic floors; (2) the small thickness of the Arenig-Llandeilo beds; but neither of these can be taken as evidence of oceanic conditions. As a matter of fact Radiolaria occur in waters of all depths, and have been found in deposits of many ages, notably in the Oxfordian and in the Lower Eocene of Northern France, in each case combined with sponge spicules to form a peculiar siliceous rock termed *gaize*. Thus the cherts and black shales of the Arenig series may be compared with the gaize and black clays of the Oxfordian, but have no resemblance to modern oceanic deposits, which are red, yellow, gray, and white, but never black. There are no fine red clays nor foraminiferal limestones among the Scottish Arenig and Llandeilo series, like those which are associated with Tertiary oceanic deposits in Barbadoes and elsewhere, and the utmost that can safely be inferred from the character and small thickness of the Scottish deposits is that they were formed in clearer water and at a greater distance from land than the Arenigs of Wales.

From this time of deep submergence there seems to have been a gradual recovery in Scotland. Thus Messrs. Peach and Horne [21] note it as "a remarkable fact that the change in the character of the sedimentation resulting from the transport of coarse terrigenous material from the north-west extends farther south with each successive period." The Caradoc conglomerate of the Lammermuir Hills, with its rounded pebbles of granite, quartzite, and graywacke, like those of the Perthshire Highlands, tell us that at length the continued uprise of the northern had brought its borders within a few miles of those hills.

References

[1] Marr and Roberts, *Quart. Journ. Geol. Soc.* vol. xli. p. 476.

[2] "Geology of North Wales," by Sir A. Ramsay, *Mem. Geol. Survey*, second edition.

[3] *Quart. Journ. Geol. Soc.* vol. xlvii. p. 371 and discussion.

[4] Ramsay, *Geology of North Wales*, second edition, p. 96.

[5] *Quart. Journ. Geol. Soc.* vol. xxxi. p. 357.

[6] "Geology of the Country between Appleby, Ullswater, and Haweswater," *Mem. Geol. Survey*, 1897.

[7] In *Geol. Mag.* Dec. 4, vol. i. p. 122.

[8] Nicholson and Marr, *Quart. Journ. Geol. Soc.* vol. xlvii. p. 500.

[9] *Geol. Mag.* Dec. 3, vol. ix. p. 97 (1892).

[10] *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 240, and vol. xxxviii. p. 538.

[11] *Geol. Mag.* Dec. 3, vol. vi. pp. 20 and 69 (1889). More detailed descriptions of the rocks are given in the "Geology of the Southern Uplands of Scotland," *Mem. Geol. Surv.* (1899).

[12] See *Summary of Progress of the Geol. Survey for 1898*, p. 57.

[13] *Summary of Progress of Geol. Survey for 1896*, p. 48.

[14] *Op. cit. Summary for 1897*, p. 71.

[15] *Sverig. Geol. Undersokn.* ser. C, No. 50 (1882-83).

[16] *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 313, and *Classification of Cambrian and Silurian Rocks* (1883).

[17] See *The Bala Volcanic Series of Carnarvonshire*, by A. Harker (1889), and *The Ancient Volcanoes of Great Britain*, by Sir Arch. Geikie, p. 195.

[18] "Geology of North Wales," *Mem. Geol. Survey*, second edition, p. 130.

[19] See *Summary of Progress of Geol. Survey for 1899*, p. 95.

[20] See the author's *Building of the British Isles*, second edition, p. 54.

[21] The "Silurian Rocks of Scotland," *Mem. Geol. Survey*, 1899, p. 53.

CHAPTER IX

SILURIAN SYSTEM

(Upper Silurian of Murchison and Geological Survey)

Nomenclature.—The reasons for restricting the name *Silurian* to the system called Upper Silurian by Murchison have been given on p. 65, but no mention was there made of a subordinate question, namely, the line of separation between the Ordovician and Silurian. Originally the whole of the strata subsequently called Llandovery Beds were included by Murchison in his Upper Caradoc group, but in 1854 Professors Sedgwick and M'Coy proved that the uppermost sandstones (to which they gave the name of May Hill Sandstone) had no connection physically or palæontologically with the Bala rocks, but formed the natural base of Murchison's (Upper) Silurian series in the typical Silurian areas.

Recognising the justice of this correction, Murchison then separated the beds from the Caradoc Sandstone (Bala), and created a new group under the name of "Llandovery rocks," subdividing it into two stages—a lower (linked by some species to the Bala series), and an upper (closely connected with the Wenlock rocks), but clearly united to one another by a community of *Pentameri* and other fossils. This Llandovery group he regarded as forming a transition series between his Lower and Upper Silurian.

Some geologists, however, objected to this arrangement on the ground that there is frequently a physical break (overlap leading to unconformity) between the Lower and Upper Llandovery, so that the latter in such localities is dissociated altogether from the former and from the Bala Beds. Consequently, Sedgwick, Jukes, and others drew the line of separation at the base of the Upper Llandovery or May Hill Sandstone. But elsewhere there is little or no want of conformity between the members of the Llandovery, while the Lower Llandovery is locally transgressive over the Bala beds. It was pointed out, however, in Chapter IV. that small

regard must be paid to such local transgressions and unconformities, unless they coincide with a palæontological break.

Recent researches have shown that the Upper Llandovery is usually succeeded by a series of pale gray and green shales (Tarannon shales), and Professor Lapworth's studies have led him to the conclusion that these three subdivisions (Lower Llandovery, Upper Llandovery, and Tarannon shales) "are far more closely allied to each other than they are to the beds above or below, and that they should be considered as the three consecutive members of a single formation."[1] The Llandoveries were formed in fact during a period of upheaval and oscillation which intervened between the quiet periods of the Bala and Wenlock beds. For their equivalents in South Scotland he has proposed the name *Valentian*, from the Roman name of that province, and Mr. Marr[2] has advocated the general adoption of this name for the lowermost group or series of the Silurian rocks in Britain.

The second natural division of the Silurian system is that which is typically developed at Wenlock in Shropshire and at Woolhope in Herefordshire. This series was described by Murchison under the name of the "Wenlock formation," and at the localities above-mentioned it consists mainly of shales with a band of limestone at the base and another at the top; but in North Wales and other parts of Britain there are no such limestones, and the only means of delimitation is by the graptolite fauna.

The third division is the "Ludlow formation" of Murchison, which in Shropshire and Herefordshire consists of shales and mudstones with a band of limestone in the middle. Although the shales below the Ludlow and Aymestry limestone were placed in this group by Murchison, he admitted that they were merely a continuation of the Wenlock series, and for some time it seemed doubtful if they could be separated from it when the Wenlock limestone was absent. Recently, however, it has been shown that they can be distinguished by their graptolites,[3] and, further, that the Aymestry limestone comes within the highest graptolite zone.

The highest beds referable to the Silurian system in the typical region are certain flagstones and sandstones which form a passage into the Old Red Sandstone, but contain fossils of Ludlow species. They may be regarded as the topmost member of the Ludlow series.

It should be mentioned, however, that Professor Lapworth has suggested a new grouping which may eventually be found more convenient. By this all the limestones and the intervening graptolitic shales are thrown into one group, for which he proposes the name *Salopian*, while the beds above the Aymestry limestone are left to form an upper group under the name of *Downtonian*. Since, how-

ever, the several districts where Silurian rocks occur in Britain have been correlated on the basis of Murchison's arrangement, the latter will be followed in these pages, and is tabulated below :—

Ludlow series	Ledbury and Downton beds.
	Upper Ludlow beds.
	Aymestry limestone.
	Lower Ludlow shales.
Wenlock series	Wenlock limestone.
	Wenlock shale.
	Woolhope limestone.
Llandovery series	Tarannon shales.
	Upper Llandovery beds.
	Lower Llandovery beds.

Life of the Period

The following is a brief synopsis of the principal genera which are found in the Silurian system.

Actinozoa.—Corals are very abundant in the limestones and calcareous beds; most of the Ordovician genera occur, *Favosites*, *Heliolites*, and *Halysites* are very common, and the following commence their existence in the British area: *Acervularia*, *Alveolites*, *Cystiphyllum*, *Clisiophyllum*, *Strombodes*, *Stauria*, and *Strephodes*: while the following have only been found in the rocks of this system, *Goniophyllum*, *Rhizophyllum*, *Thecia*, *Omphyma*, and *Palæocyclus*.

Hydrozoa.—Graptolites are abundant in the lower beds, but gradually decrease in numbers and almost die out in the upper beds. The family Monograptidæ, including the genera *Monograptus*, *Cyrtograptus*, and *Rastrites*, appears to be confined to the Silurian, and the only other families represented are the Diplograptidæ and Retiolitidæ. Stromatoporoids become abundant in the Silurian, and are associated with corals as important rock-builders. The principal genera are *Stromatopora*, *Labechia*, and *Clathrodictyon*.

Echinoderma.—Of this class the crinoids are by far the most abundant, more than fifty species having been found in British Silurian strata. The following genera are specially characteristic of the Silurian: *Callicrinus*, *Clonocrinus Crotalocrinus*, *Encrinus*, *Herpetocrinus*, *Marsupiocrinus*, *Pisocrinus*, and *Periechocrinus;* and besides these the genera *Cyathocrinus*, *Ichthyocrinus*, *Encalyptocrinus*, *Hapalocrinus*, and *Taxocrinus* make their first appearance. Cystideans continue to occur, and the genera *Lepadocrinus*, *Placocystis*, *Pseudocrinus*, *Pronocystis*, and *Schizocystis* are specially characteristic of the Silurian period. An Echinid, the genus *Palæchinus*, makes its appearance.

Crustacea.—Trilobites, though not quite so numerous as in the Ordovician, continue to be common, most of the species belong-

ing to the genera *Calymene*, *Phacops*, *Encrinurus Harpes*, *Acidaspis*, *Illænus*, *Homalonotus*, *Lichas*, *Cheirurus*, *Proetus*, and *Deiphon*, the last only being exclusively Silurian.

Besides trilobites, another remarkable and extinct order of Crustacea makes its appearance—the *Merostomata*—with the genera *Eurypterus*, *Pterygotus*, *Stylonurus*, *Hemiaspis*, and *Neolimulus*.

Brachiopoda are remarkably abundant. Most of the Ordovician genera recur, such as *Lingula*, *Orthis*, *Leptæna*, *Rhynchonella*,[a] *Strophomena*, and *Triplecia;* and the following genera make their first appearance: *Atrypa*, *Athyris*, *Chonetes*, *Dayia*, *Glassia*, *Cyrtia*, *Cyrtina*, *Pentamerus* (*Conchidium*), *Stricklandia*, *Rhynchotreta*, *Retzia* (*Rhynchospira*), and *Spirifer*.

Lamellibranchia.—Members of this class also become more abundant in the Silurian period, about 100 species being known in England belonging chiefly to the following genera, *Cardiola*, *Cardiomorpha*, *Ctenodonta*, *Orthonotus*, *Cleidophorus*, *Grammysia*, *Ambonychia*, *Pterinæa*, *Conocardium*, *Lunulicardium*, and *Modiolopsis*.

Gastropoda are also fairly numerous, about sixty species being known from the English Silurians. Most of them are referable to the following genera: *Pleurotomaria*, *Murchisonia*, *Bellerophon*, *Platychisma*, *Trochus*, *Omphalotrochus* (*Horiostoma*), *Cyclonema*, *Eunema*, *Holopea*, *Holopella*, *Platyceras* (= *Acroculia*), and *Subulites*. The last genus is noteworthy as possessing a channelled mouth, all the rest being holostomous.

Cephalopoda.—These are also numerous, and include species of *Orthoceras*, *Phragmoceras*, *Gomphoceras*, *Trochoceras*, *Lituites*, *Cyrtoceras*, *Actinoceras*, and *Ascoceras*, the last being only known as a Silurian form.

Fishes.—The earliest remains of vertebrate animals hitherto found in Britain occur in the Ludlow series, and are the remains of fish belonging to the class or order *Agnatha*. The chief genera are: *Pteraspis*, *Cephalaspis*, *Auchenaspis*, and *Scaphaspis* (all Placoderms and known from their bony dermal plates), *Eukeraspis* and *Onchus* (spines), and shagreen-like plates referred to *Sphagodus* and *Thelodus*.

The greater part of the Silurian system is capable of subdivision into zones by means of the graptolite faunas, and though these are not equally developed in all localities they always occur in the same order of succession. No species have yet been recognised in the Upper Ludlow beds, but from the Aymestry limestone downward the following zones have been recognised :—

[a] Messrs. Hall and Clarke have shown that many of the Palæozoic Rhynchonellas differ from the Mesozoic types, and are more properly referred to new genera. They doubt if a true Rhynchonella existed in Palæozoic times, but this view is not yet accepted in England.

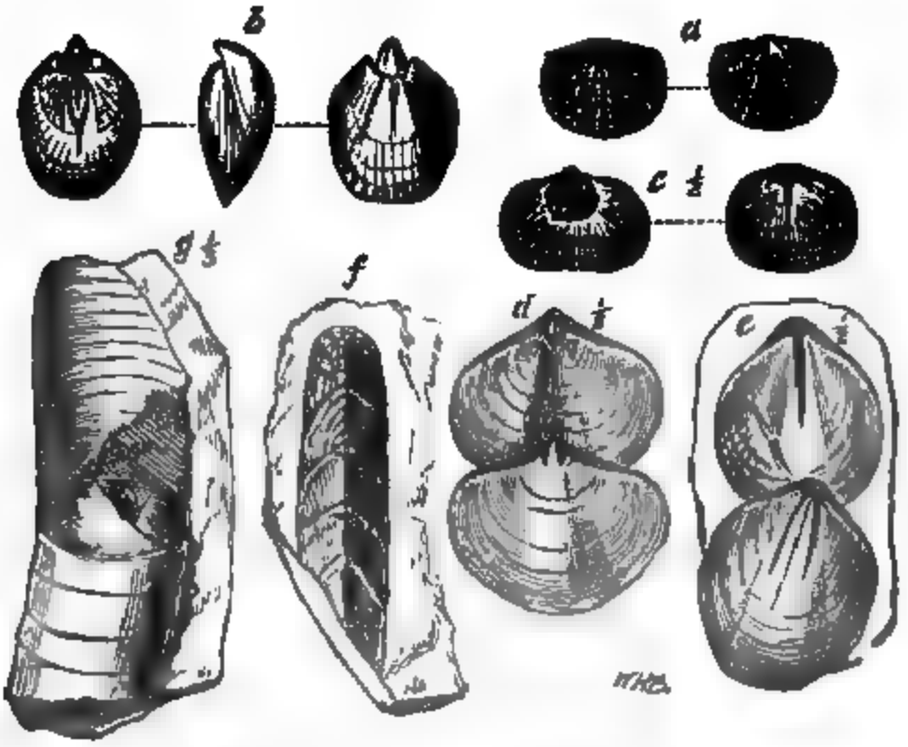

Fig. 38.—GROUP OF LLANDOVERY FOSSILS.

a. Atrypa hemispherica.
b. Meristella angustifrons.
c. Orthis reversa.
d. Strickland'nia lens.
e. Pentamerus oblongus.
f. Chiton Griffithi.
g. Cyrtoceras approximatum.

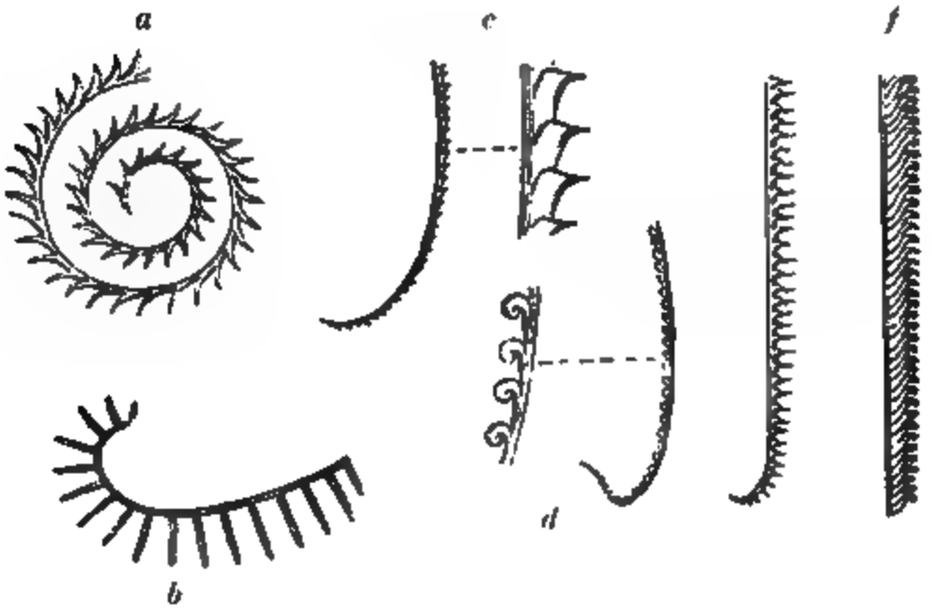

Fig. 39.—SILURIAN GRAPTOLITES.

a. Monograptus spiralis.
b. Rastrites peregrinus.
c. Monograptus gregarius.
d. Monograptus exiguus.
e. Monograptus Sedgwicki.
f. Monograptus priodon.

Lower Ludlow	Zone of	Monograptus leintwardinenis.
	,,	,, tumescens.
	,,	,, scanicus.
	,,	,, Nilssoni.
	,,	,, vulgaris.
Wenlock Beds	,,	Cyrtograptus Lundgreni.
	,,	,, rigidus.
	,,	,, Linnarssoni.
	,,	,, symmetricus.
	,,	Monograptus riccartonensis.
	,,	Cyrtograptus Murchisoni.
Valentian (Llandovery)	,,	,, Grayæ.
	,,	Monograptus crispus and M. exiguus.
	,,	Rastrites maximus.
	,,	Monograptus spinigerus and Cryptograptus cometa.
	,,	,, gregarius.
	,,	Diplograptus acuminatus and vesiculosus.

The following are some of the other fossils which are specially characteristic of each of the three Silurian series or divisions :—

Fossils of the Llandovery and Valentian Series

Actinozoa. Petraia bina, Lindstrœmia subduplicata, Pinacopora Grayi.
Hydrozoa. (See table of graptolite zones).
Echinoderma. Palæchinus Phillipsi (but none are common).
Crustacea. Illænus æmulus, Phacops Weaveri, Proetus Stokesi.
Brachiopoda. Lingula Crumena, Atrypa hemispherica, Meristella crassa, M. angustifrons, Stricklandia lens, Pentamerus oblongus, P. undatus, Orthis reversa.
Lamellibranchia. Ctenodonta Eastnori, Orthonota amygdalina, and O. inornata (both range into Wenlock).
Gastropoda. Turbo tritorquatus, Holopella cancellata, Omphalotrochus prenuntius.
Cephalopoda. Tretoceras bisiphonatum, Cyrtoceras approximatum, Orthoceras conicum.

Fossils of the Wenlock Series

Actinozoa. Acervularia luxurians, Arachnophyllum typus, Strombodes diffluens, Cyathophyllum truncatum, Omyphyma turbinatum, Heliolites interstinctus (from Bala), H. Grayi, Favosites gottlandicus.
Hydrozoa. (See table of graptolite zones).
Echinoderma. Actinocrinus (Glytocrinus ?) pulcher (from L. Llandov.), Periechocrinus moniliformis, Crotalocrinus rugosus, Marsupiocrinus cælatus, Lepadocrinus quadrifasciatus.
Crustacea. Illænus barriensis, Phacops caudatus (Val. to Lud.), P. Downingiæ, Calymene Blumenbachii (Bala to Lud.), Encrinurus punctatus (Bala to Lud.), Lichas anglicus (to Lud.).
Brachiopoda. Atrypa reticularis, Pentamerus galeatus, Strophomena euglypha, S. rhomboidalis (Llan. to Lud.), Orthis rustica, O. elegantula (Bala to Lud.), Spirifer plicatellus, Retzia Barrandi, Rhynchonella borealis, Cyrtia exporrecta.

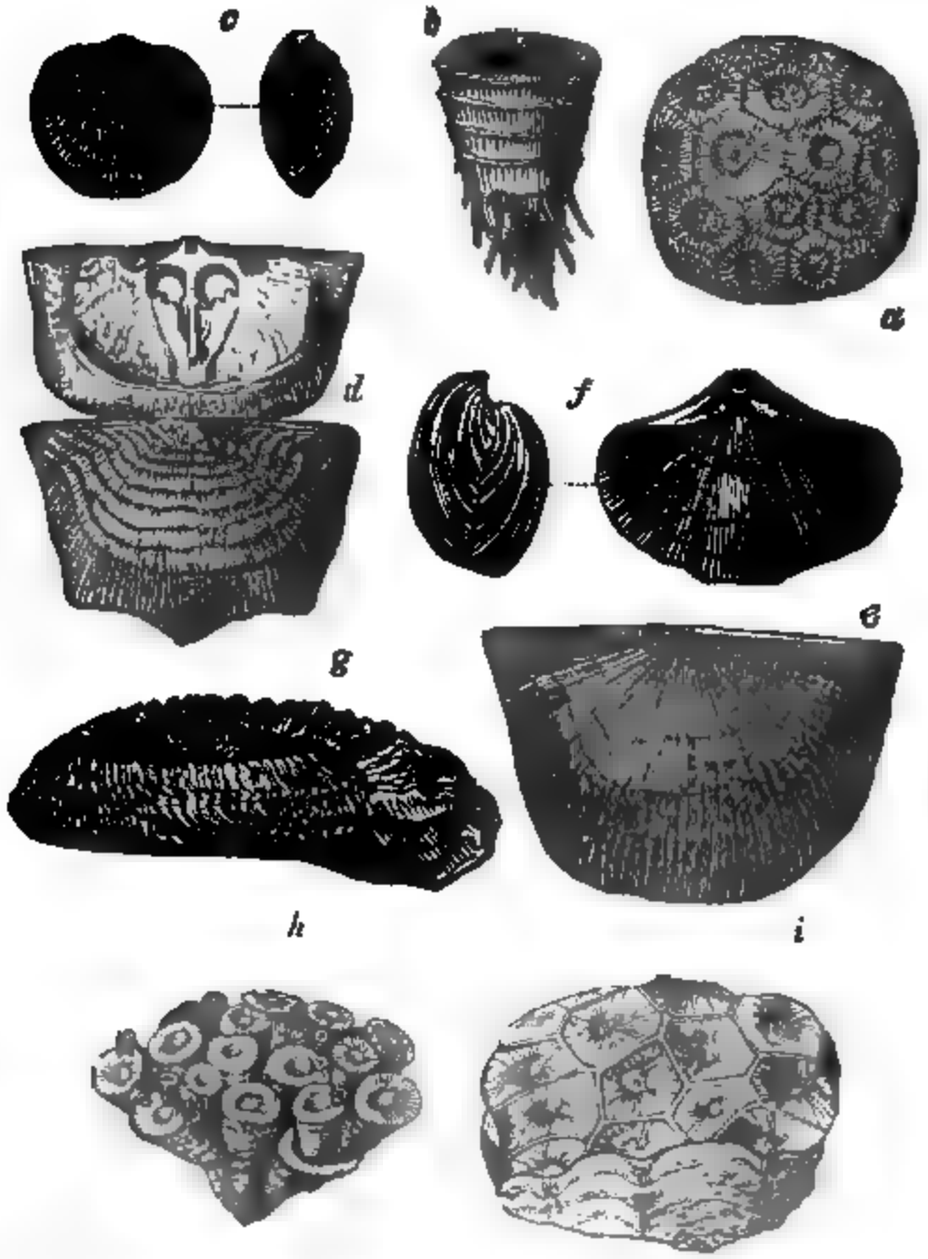

Fig. 40.—GROUP OF WENLOCK FOSSILS.

a. Acervularia luxuriana.
b. Omphyma turbinatum.
c. Atrypa reticularis.
d. Strophomena rhomboidalis.
e. Strophomena euglypha.
f. Spirifer plicatellus.
g. Horiostoma discors.
h. Cyathophyllum truncatum.
i. Arachnophyllum typus.

Lamellibranchia. Cardiola interrupta, Grammysia cingulata.
Gastropoda. Horiostoma discors, H. rugosus, Eunema cirrhosus, Platyceras (Acroculia) haliotis, Bellerophon dilatatus.
Cephalopoda. Orthoceras primævum, O. annulatum, Phragmoceras ventricosum, Gomphoceras pyriforme.

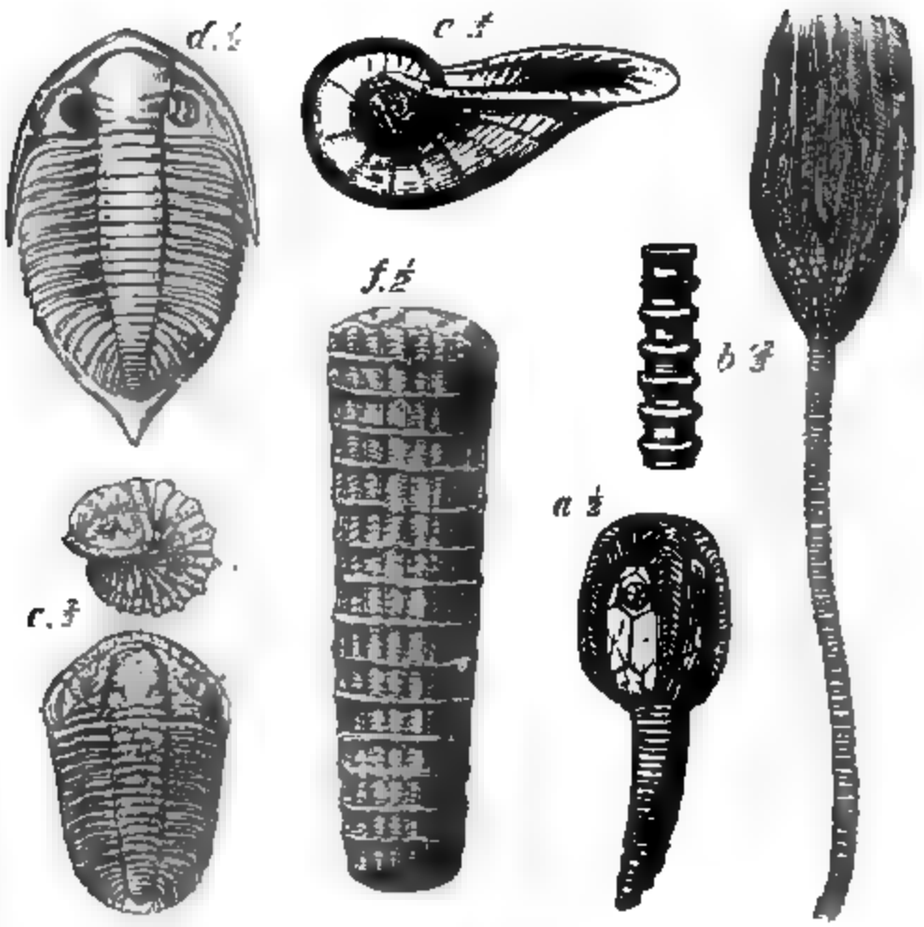

Fig. 41.—GROUP OF WENLOCK FOSSILS.

a. Lepadocrinus quadrifasciatus.
b. Periechocrinus moniliformis.
c. Calymene Blumenbachi.
d. Phacops caudatus.
e. Bellerophon dilatatus.
f. Orthoceras annulatum.

Fossils of the Ludlow Series

Porifera. Ischadites Kœnigi, Favospongia Ruthveni.

Echinoderma. Ichthyocrinus pyriformis (from Wenlock), Lapworthura Miltoni, Palæaster Ruthveni, Palæocoma Colvini.

Crustacea. Homalonotus delphinocephalus (from Wenl.), H. Knighti, Acidaspis coronata, A. Hughesi, Pterygotus arcuatus, Eurypterus abbreviatus, Hemiaspis limuloides.

Brachiopoda. Pentamerus Knighti, Dayia navicula, Rhynchonella nucula (from Val.), Orthis lunata, Chonetes striatella (and var. lata), Discina rugata, Lingula cornea, L. Lewisi (from Wenl.).

Lamellibranchia. Avicula Danbyi (from Val.), Pterinea retroflexa, Cardiola striata, and C. interrupta (both from Wenl.), Orthonota semisulcata.

Gastropoda. Cyclonema coralli, Murchisonia coralli, Holopella gregaria, Platychisma helicites.

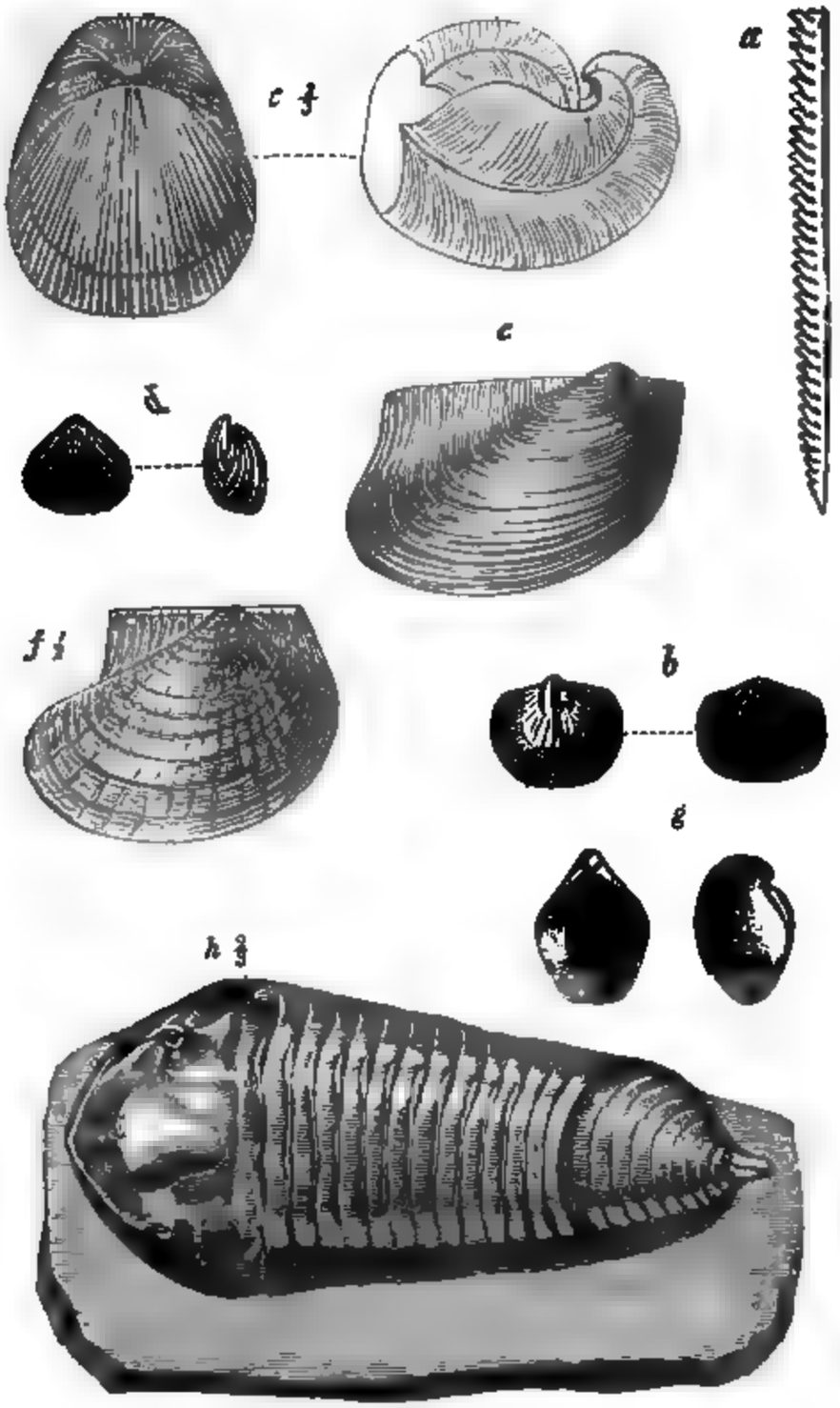

Fig. 42.—GROUP OF LUDLOW FOSSILS.

a. Monograptus priodon.
b. Orthis lunata.
c. Pentamerus Knighti.
d. Rhynchonella nucula.
e Pterinea retroflexa.
f. Avicula Danbyi.
g. Bayia navicula.
h. Homalonotus delphinocephalus.

CORRELATION TABLE OF SILURIAN ROCKS

	Shropshire, Hereford, etc.	Radnor and South Wales.	North Wales.	Westmoreland.	South Scotland. Southern Belt.	South Scotland. Northern Belt.
Ludlow Series.	Ledbury shales, Downton sandstone, Up. Ludlow shale, Aymestry limestone and Lower Ludlow shales, 1800 feet.	Tilestones, Clun flags, Graptolite zones of Lower Ludlow, 3000 feet.	Absent. Moel Gaiol and Dinas Bran beds, Micaceous flags and Nantglyn flags, 4000 feet.	Kirkby Moor flags, Bannisdale slates, Coniston grits, Coldwell flags, 12,000 feet.	Not seen.	Conglomerate and red and green mudstones. Red sandstones and conglomerate. Mudstones and shales of Lanark and the Pentlands, 4000 feet.
Wenlock Series.	Wenlock limestone, Wenlock shale, Woolhope limestone, 2000 feet.	Shales with Cyrt. Lundgreni, Shales and flagstones, Shales with Cyrt. Murchisoni, 2400 feet.	Moel Ferna beds, Pen-y-glog grit, Pen-y-glog slates, Cyrt. Murchisoni, 1700 feet.	Coldwell grits, Brathay flags, 2500 feet.	Raeberry beds, 500-700 feet. Riccarton beds, 1000-1500 feet. Total, over 2000 feet.	*Girvan Area.* Upper Wenlock in Lanark, 2200 ft. Straiton and Bargany beds in Ayrshire, 900 ft. Total, over 3000 feet.
Llandovery Series.	Tarannon shales, May Hill sandstone, and Up. Llandovery, 1000 feet. Absent.	Tarannon shales, Upper Llandovery and Caban group. Lower Llandovery (Gwastaden group) 3000-4000 feet.	Tarannon shales, Graptolitic mudstones, Corwen grits, 900 feet.	Browgill beds, Skelgill beds, 250 feet.	Gala series. Birkhill shales, 3100 feet.	Parkhill group, Camregan group, Saugh Hill group, Mullock Hill group, 2000 feet.

Cephalopoda. Orthoceras bullatum, O. ludense, Lituites giganteus, Ascoceras Barrandi.

Pisces. Scaphaspis ludensis, Cephalaspis ornatus, Auchenaspis Salteri.

Exposed Areas and Geographical Range

In South Wales the Silurians emerge from beneath the overlapping Old Red Sandstone west of Narberth, and form a narrow strip (the beds being nearly vertical) for a long distance between the Ordovician and Old Red Sandstone areas. Near Builth the dip becomes less, and the Silurian outcrop widens rapidly, till in the Radnor and Clun Forest districts it is from 12 to 25 miles wide. Moreover, a prolongation of the great Caradoc fault repeats the series along a tract extending from Presteign by Wenlock Edge to Coalbrookdale. From Radnor the main outcrops run through Montgomery and surround the periclinal dome of the Berwyn Mountains; thence they pass into Denbighshire, and occupy the country between the valleys of Dee, Clwyd, and Conway.

In the south-east of Wales (Cardiff and Usk), as well as at Malvern and other localities in Gloucester, Hereford, Worcester, and Stafford, the Silurians are brought up again to the surface by anticlinal or periclinal flexures, forming isolated tracts or inliers, surrounded on all sides by younger rocks. Silurian rocks have also been proved to occur beneath the Cretaceous beds in Hertfordshire; it is probable, therefore, that they have a very considerable subterranean extension in the centre and east of England.

In the Lake District the Silurian rocks lie to the south-east of the Ordovician region in Westmoreland, reaching from the estuary of the Duddon by Coniston Water and Windermere to the valley of the Kent north of Kendal, occupying the upper valley of the Lune as far south as Kirkby Lonsdale in Lancashire (see map, Fig. 32).

In Scotland Silurians occur along with the Ordovician throughout the southern uplands. Wenlock and Ludlow beds occur in the Pentland Hills, and also in Lanark. No Silurian rocks have yet been found in the more northern parts of Scotland.

1. *Shropshire and Radnorshire*

We shall consider this district to embrace all the country lying between the valley of the Severn on the north-west and north and

the boundary of the Old Red Sandstone on the west and south-west. This area is taken first because it is that in which the Silurian sequence was first established by Sir R. Murchison, and includes most of the places after which the subdivisions were named, so that it has come to be regarded as a classical and typical area. It is also interesting because within its limits the more calcareous facies of the formation can be traced into its argillaceous facies, and because it exhibits the proofs of a great unconformity.

The northern part of the area is divided into a western and an eastern portion by the intervening tract of Ordovician and Longmyndian rocks, but in the southern part the Silurian beds unite to form a broad tract of country extending to Clun, Kington, Presteign, and Rhyader, and supporting several outliers of the Old Red Sandstone.

The general strike of the Silurian rocks is from north-east to south-west, and in the eastern part of the district the prevalent dip is to the south-east. The succession of the rock-groups in the Wenlock and Ludlow district is shown in Fig. 44.

Llandovery Beds.—The complete series of Llandovery Beds is only found within the western part of the area near Rhyader in Radnor, and has recently been worked out by Mr. H. Lapworth, from whose account the following is taken.[4] He describes the Lower Llandovery under the name of the Gwastaden group, the Upper Llandovery as the Caban group, and the Tarannon shale as the Rhyader pale slates. The Gwastaden beds seem to succeed the Bala beds without any break, but there is a strong unconformity between the Gwastaden and Caban groups, and the latter is overlapped by the Rhyader slates, so that the structure of the district is somewhat complicated. Fig. 43 is one of the figures given by Mr. Lapworth, and is a diagrammatic view of the succession and of the relations of the rock-groups when faults and folds are eliminated.

He estimates the thickness of the Gwastaden series at over 1000 feet, that of the Caban group as 1500 (maximum); that of the Rhyader (Tarannon) slates is not given, but they extend over a large area of ground between Rhyader and Llanidloes, where they are probably 1500 feet thick, so that in this district the Llandovery or Valentian series has a total thickness of nearly 5000 feet.

When traced eastward or south eastward the Gwastaden series are found to thin out entirely and the thickness of the Caban beds and Tarannon shales is greatly reduced. North-east of Builth they form quite a narrow band and rest unconformably on Llandeilo slates. At Corton near Presteign coarse brown Llandovery grits rise from beneath purple shales which are probably Tarannon beds,

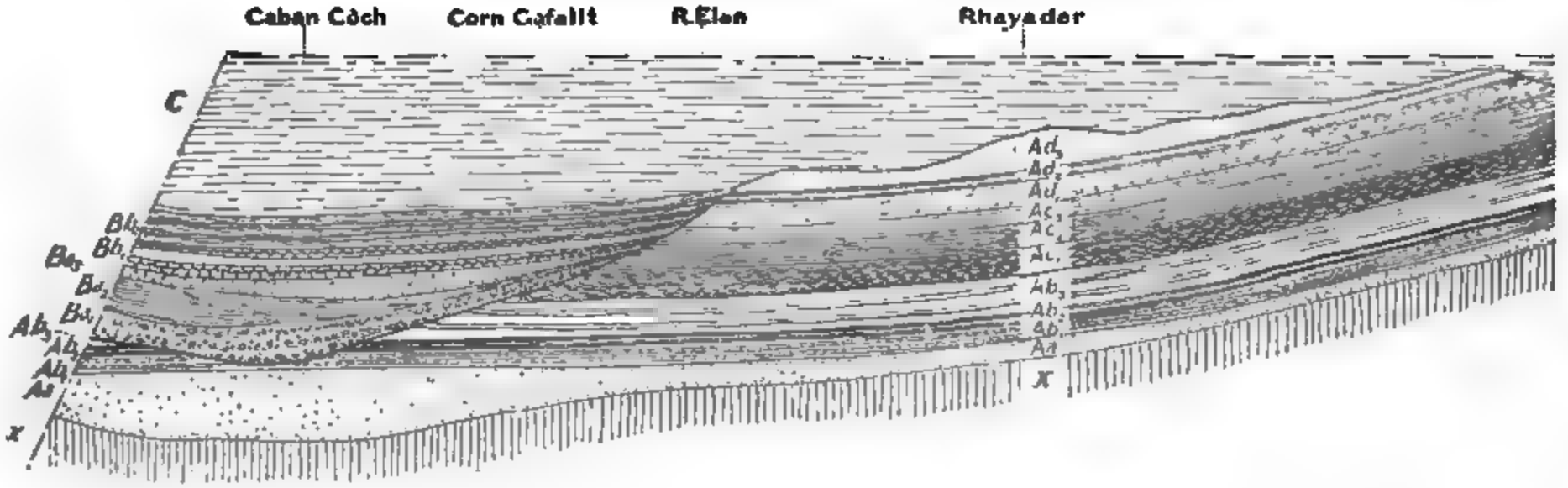

Fig. 43.—DIAGRAMMATIC SECTION THROUGH RHYADER TO SHOW THE RELATION OF THE UPPER TO THE LOWER LLANDOVERY (by H. Lapworth). The Rhyader slates are plotted as lying horizontally. From *Quart. Journ. Geol. Soc.* vol. lvi. p. 122. Distance about 7 miles.

C. Rhyader pale slates (Tarannon).
B. Members of the Caban group.
A. Members of the Gwastaden group.
x. Blue-black shales (? Bala).

but the base is not exposed. When the group again emerges on Shropshire it consists of the following members :—

Purple shales (=Tarannon Shale) . . .	200 to 400 feet.
Pentamerus limestone	30 to 40 ,,
Basement grits and conglomerates . . .	0 to 120 ,,

The basement beds rest unconformably on Ordovician, Cambrian and Longmyndian in different parts of the area, varying greatly in thickness and in places thinning out altogether so as to leave the overlying limestone in contact with the older rocks. Thus the Pentamerus limestone is really a sandstone rendered calcareous by the quantity of included fossil shells. The commonest fossils are *Pentamerus oblongus*, *P. undatus*, *Stricklandia lens*, *Atrypa hemispherica*, *Strophomena pecten*, *Encrinurus punctatus*. The overlying shales consist in the Wenlock district of purple, red, and green shales with few fossils, and are distinguishable by their colours from the overlying Wenlock shales.

Wenlock Series.—These beds are well exposed along the tract which extends from Downton to the river Severn at Coalbrookdale, where they form the escarpment ridge known as Wenlock Edge (see Fig. 44). The best account of the succession here found is that given by Mr. Maw in 1881 and confirmed by Professor Lapworth.[5]

The lowest barren shales of Mr. Maw probably include the Tarannon Shales, so that the thickness of the Wenlock series will not be more than 200 feet. The Buildwas beds are exposed in a small cliff opposite Buildwas Abbey, and are shales which yield an immense number of small brachiopoda, *Orthis biloba*, *O. elegantula*, *O. Lewisi*, *O. hybrida*, *Leptæna segmentum*, *Nucleospira pisum*, and *Atrypa Barrandi*. Mr. Maw considered these beds to represent the Woolhope Limestone of more southern localities. The Tickwood beds are shales with layers of nodular limestone, the shales predominating in the lower part and the limestones in the higher part below the massive limestone of Wenlock edge, so that it is not easy to say where the one ends and the other begins. Fossils are abundant in these beds.

The Wenlock Limestone is well exposed at Benthall Edge and in quarries near Wenlock ; it is a gray earthy limestone, generally lying in thin beds with shaly partings, and is highly fossiliferous. Some of the beds appear to be largely made up of corals which weather out finely in the spoil-heaps, while others contain quantities of Brachiopoda and Mollusca. The first 100 feet of shales above the limestone form a passage from the Wenlock to Ludlow beds, many Wenlock species ranging up into them, while they also contain

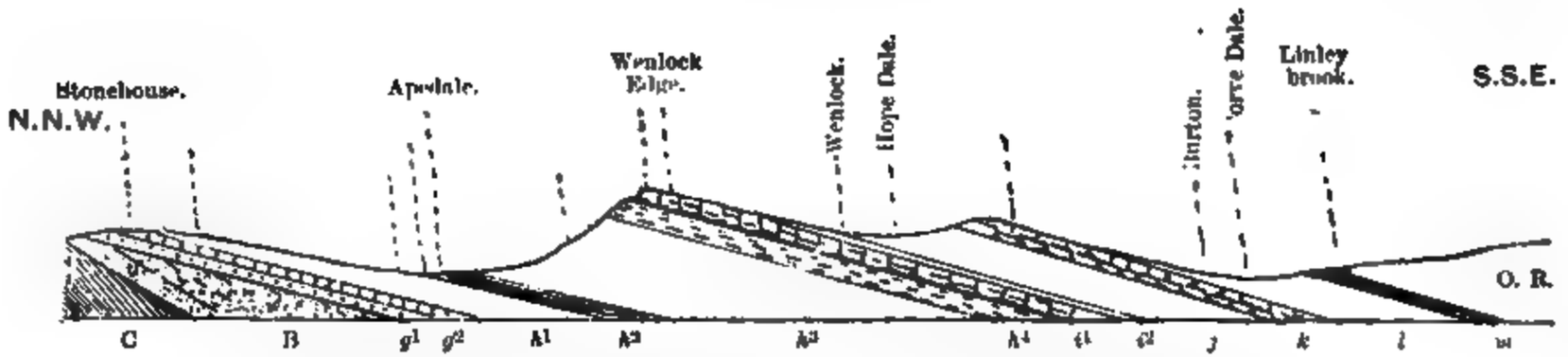

Fig. 44.—SECTION THROUGH THE SILURIAN ROCKS OF SHROPSHIRE (Maw and Lapworth).

O. R. Old Red Sandstone.
m, Passage beds . . . 300 feet.
l, Upper Ludlow . . 600 ,,
k, Aymestry limestone 150 ,,
j, Lower Ludlow . . 800 ,,
*i*², Shales over limestone . 100 feet.
*i*¹, Wenlock limestone 80 to 90 ,,
*h*⁴, Tickwood beds . 300 to 400 ,,
*h*³, Barren shales . 1100 to 1200 ,,
*h*², Buildwas beds . 80 to 100 ,,
*h*¹, Barren shales . 500 to 600 feet.
*g*², Pentamerus limestone . 30 ,,
*g*¹, Llandovery grits . . 40 ,,
B, Hoar Edge grits (Bala beds).
C, Shineton shales (Tremadoc).

Horizontal scale 1 inch = 1 mile. The localities are not all on the same line.

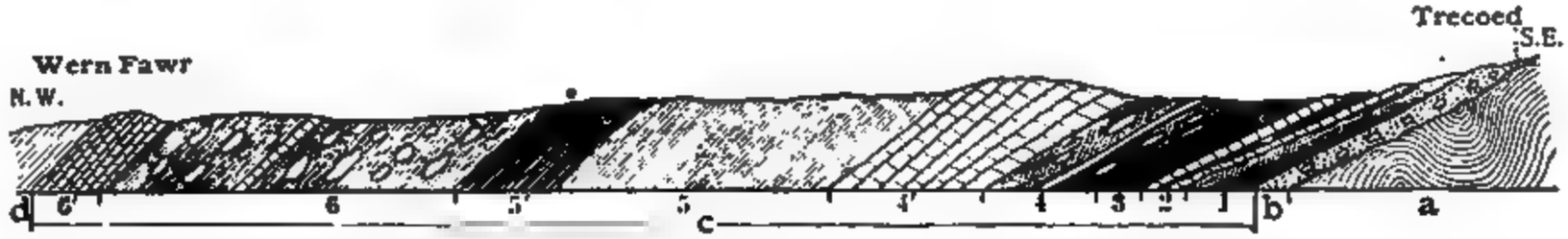

Fig. 45.—SECTION FROM WERN FAWR TO TRECOED NEAR BUILTH (Miss Elles).

d. Ludlow beds.
c. Wenlock shales.
b. Llandovery beds.
a. Llandeilo beds.
6'. Flagstones.
6. Zone of *Cyrt. Lundgreni.*
5. Zone of *Cyrt. rigidus.*
4'. Flagstones.
4. Zone of *Cyrt. Linnarssoni.*
3. Zone of *Cyrt. symmetricus.*
2. Zone of *Mon. riccartonensis.*
1. Zone of *Cyrt. Murchisoni.*

Rhynchonella Wilsoni, *Strophomena furcillata*, and *Chonetes lepisma*, which are Ludlow forms.

When the beds are traced south-westward to Presteign and Aymestry the Wenlock Limestone is found to diminish greatly in thickness, while another band of limestone sets in for a space at a lower level; this is the Woolhope Limestone; but when the beds are traced westward from Presteign into Radnor both these limestones thin out and leave a continuous series of shales and mudstones.

The subdivision of this mudstone series was practically impossible so long as lithological differences only were relied upon as a means of classification, but in 1880 Professor Lapworth drew attention to the graptolite fauna of these beds, and expressed the belief that "by the aid of the lowly graptolite the geologist of the future will be able to read off the natural succession" of the monotonous Silurian mudstones. This has recently been accomplished in Radnorshire and West Shropshire by Miss G. L. Elles[6] and Miss E. M. R. Wood,[7] the former dealing with the Wenlock succession and the latter with the Lower Ludlow.

The country round Builth may be taken as the type of this graptolitic facies of the Wenlock series, and Miss Elles has shown that it contains a fauna of twenty-three species and varieties of graptolites, by means of which it can be divided into six zones. The succession of the beds is shown in Fig. 45, which is taken by permission from her paper. The total thickness appears to be about 2500 feet, but there are two partial breaks in the series, for the flagstones of zone 4 overlap the beds below, so that in one place they rest on the lower part of zone 2, and again, there is reason to think that the upper beds of zone 5 are sometimes concealed by an overlap of zone 6 (*Cyrtograptus Lundgreni*), which represents the Wenlock limestone.

Ludlow Series.—The Lower Ludlow shales consist of soft gray sandy shales, often showing a tendency to spheroidal structure, and their total thickness is about 900 feet in the Wenlock and Ludlow district. In the Wenlock area they do not contain graptolites, but have yielded many other fossils, of which the following are some of the commonest: *Lingula lata*, *Rhynchonella Wilsoni*, *Rh. nucula*, *Leptæna lævigata*, *Chonetes striatella*. At the top of these shales there are some beds of earthy flagstone which are quarried and are known as the Leintwardine flags; they contain remains of starfish (*Lapworthura* and *Palæocoma*), large *Orthoceras*, and Arthropods of the genera *Pterygotus* and *Eurypterus*.

The Aymestry Limestone is a bluish gray earthy limestone of varying thickness, and often split into several beds by intercalated

bands of shale; at Aymestry it is well exposed in the gorge of the river Lugg, and is said to be 175 feet thick. Its commonest fossils are: *Lingula Lewisi*, *Pentamerus Knighti*, *Rhynchonella Wilsoni*, and *Dayia navicula*. The map, Fig. 46, shows the outcrops

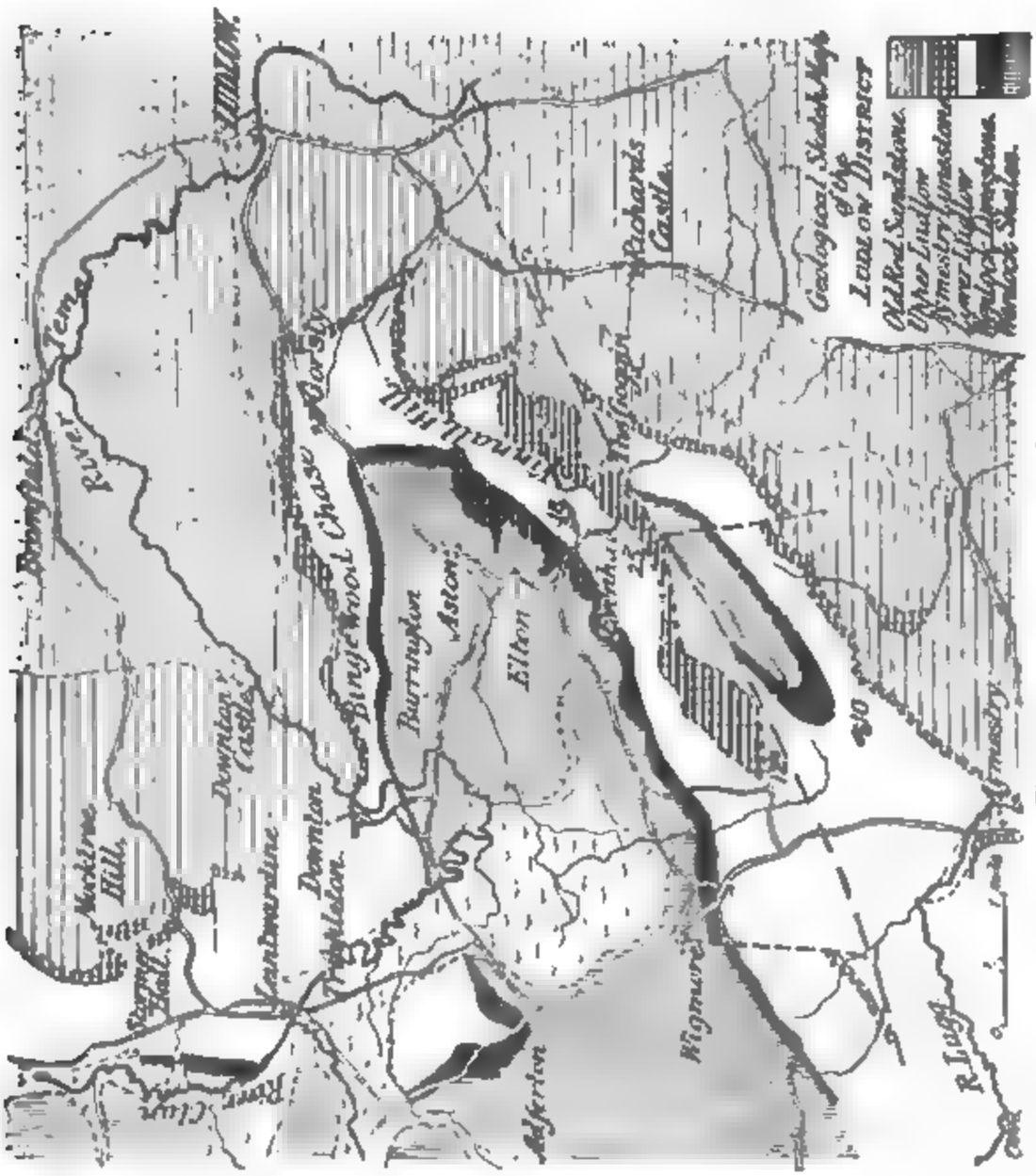

Fig. 46.—MAP OF THE LUDLOW DISTRICT.

of the Ludlow beds near Leintwardine, Ludlow, and Aymestry, and is borrowed by permission from Miss Wood's paper above mentioned.

The Upper Ludlow shales consist principally of soft gray shaly mudstones, generally weathering brown, with thin layers of earthy

limestone. They are well exposed near Ludlow, where they are probably from 500 to 600 feet thick, and they contain *Lingula minima*, *Discina rugata*, *Orthis lunata*, *Dayia navicula*, and *Homalonotus Knighti*. At the top of these mudstones is a bed of greenish gray argillaceous sandstone surmounted by greenish laminated sandstones, including a thin layer consisting of the bones and spines of fish and large Crustacea; this layer is known as the "bone bed," and has been met with at many localities.

The bone bed is succeeded by the Downton sandstone, a fine-grained and thin-bedded yellowish sandstone, which is quarried for building stone at Downton Castle near Ludlow, and contains *Lingula cornea*, *Pteraspis Banksi*, *Eurypterus lineatus*, and other Merostomata. This is about 80 feet thick, and is succeeded by reddish flagstones and olive green shales which yield *Lingula cornea* with remains of fish and Crustacea. The highest beds are purple sandstone still containing *Lingula cornea*, and the total thickness of the group is believed to be 300 feet.[8]

The Ludlow series maintains a similar facies as far as Aymestry and Presteign, but when traced into Radnor the limestone band is reduced to a few thin and interrupted layers, some beds consisting mainly of *Pentamerus Knighti* and others of the small *Dayia navicula*. But at the same time graptolites begin to be abundant in the lower shales, and the graptolite fauna of these beds has been studied by Miss E. M. R. Wood, who finds that near Ludlow and again at Builth the Lower Ludlow shales can be divided into five zones by means of the graptolites, the descending succession being as follows :—

	Feet.
5. Zone of *Monograptus leintwardinensis*, including the Aymestry limestone	400 to 500
4. Zone of *Monograptus tumescens*	100 to 220
3. Zone of *Monograptus scanicus*	250 to 100
2. Zone of *Monograptus Nilssoni*	300 to 400
1. Zone of *Monograptus vulgaris*	
	1050 to 1220

In the country round Kington, Clun, and Radnor Forest these graptolitic shales are succeeded by a great thickness of brownish sandy shale with beds of brown flagstone and sandstone, which are shown in the sections of the Geological Survey to be from 1700 to 2000 feet thick. In this district, therefore, the Ludlow series appears to be about 3000 feet thick.

2. *South Wales*

This district includes the continuation of the main outcrop through Caermarthenshire from near Llandovery to the south-west, together with some exposures in Pembrokeshire and the inlying tracts near Cardiff and Usk.

Llandovery Series.—Near the town of Llandovery both the upper and lower groups of this series are well developed. The lower group is about 1000 feet thick and contains many fossils, such as *Orthis elegantula* and other species, *Meristella crassa*, *Pentamerus oblongus*, *Strophomena pecten*, corals, and trilobites. The upper group is from 300 to 700 feet thick and is also fossiliferous, about 70 per cent of the species being common to both groups. The junction of the two groups can be seen at Noeth Grug, and is there apparently conformable, but the upper group overlaps the lower elsewhere. In Pembrokeshire they crop out here and there from beneath the overlapping Old Red Sandstone, as near Haverfordwest,[9] but they are not exposed in the Cardiff or Usk inliers.

Wenlock Series.—The Llandoveries are succeeded by the Wenlock shales, but as the lower part of these shales is overlapped by the higher zones (see p. 148), and as near Llangadock the Lower Ludlow shales pass over part of the Wenlock series, according to the observations of Miss E. M. R. Wood (*op. cit.* p. 440), the outcrop of the Wenlocks is gradually narrowed. This series, however, reappears in the inliers of Cardiff and Usk (see below).

Ludlow Series.—The Builth type of Ludlow beds can be followed southward to Llangadock, but between that place and Caermarthen they are overlapped by the Old Red Sandstone. In the Cardiff inlier the following sequence was described by Professor Sollas.[10]

		Feet.
Ludlow, 364 feet	Grit bed with fish remains.	
	Upper Ludlow, gray and brown mudstones with *Orthis lunata*, *Chonetes striatella*, etc.	74
	Concealed beds	140
	Lower Ludlow, sandstones and shales with fossils	150
Wenlock, 599 feet	Calcareous sandstones with thin beds of limestone and shale (Wenlock fossils)	38
	Flaggy sandstones and thin bed of limestone	74
	Sandstones and shales	107
	Massive yellow sandstones (Rhymney grit)	70
	Greenish gray mudstones and sandstones	310
		963

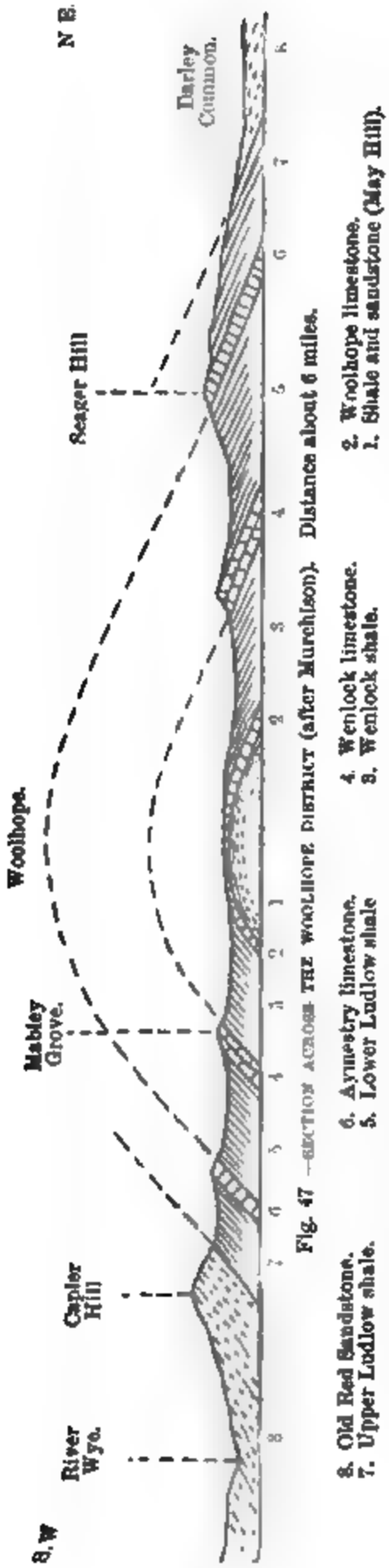

Fig. 47.—SECTION ACROSS THE WOOLHOPE DISTRICT (after Murchison). Distance about 6 miles.

It is noticeable that the thickness of the Ludlow series is here very small, and though Mr. Strahan has since found reason to include in it some of the beds placed by Mr. Sollas in the Old Red Sandstone, still these can only represent the Downton beds, and the thickness of the Ludlow proper has diminished from 1450 to 364 feet.

In the Usk district the thickness of the combined Ludlow and Wenlock series so far as exposed is about 1200 feet, and the Wenlock limestone is more defined, and in places has a thickness of 20 to 30 feet of successive limestones.

3. *The Eastern Inliers*

These are all inlying tracts of no great width brought up by anticlinal flexures or faulted upthrows, and surrounded by tracts of newer rocks. There are eight of these inliers — those of Tortworth, May Hill, Woolhope, Malvern, Abberley Hills, Lickey and Rubery, Dudley Hills, and Walsall.

The general facies of the beds at all these places is similar, and resembles in the main that found near Ludlow and Aymestry, the monotony of the shales and mudstones being broken by three bands of limestone, the Woolhope, the Wenlock, and the Aymestry limestones, which form bold escarpments, and give rise to very picturesque scenery (see Fig. 47).

The most complete succession is found in the Malvern, May Hill, and Woolhope areas, and it will suffice to give some account of the

first of these. The Malvern Hills consist of a tract of Cambrian and Pre-Cambrian rocks (see Figs. 48 and 49) which are faulted on the eastern side against Triassic sandstones, so that the Silurian strata are only exposed on the western side.

Fig. 48.—GENERAL SECTION THROUGH THE SILURIAN SERIES NEAR MALVERN

j. Old Red sandstone.
i. Ledbury shales.
h. Aymestry limestone.
g. Lower Ludlow shales.
f. Wenlock limestone.
e. Wenlock shale.
d. Woolhope limestone.
c, b. May Hill sandstone.
a, x. Pre-Cambrian rocks.

Llandovery Beds.—The Lower Llandovery is not represented in this region, the lowest beds being of Upper Llandovery age and known as the May Hill sandstone. This group is about 1000 feet thick, and consists of (1) a lower set of sandstones and conglomerates

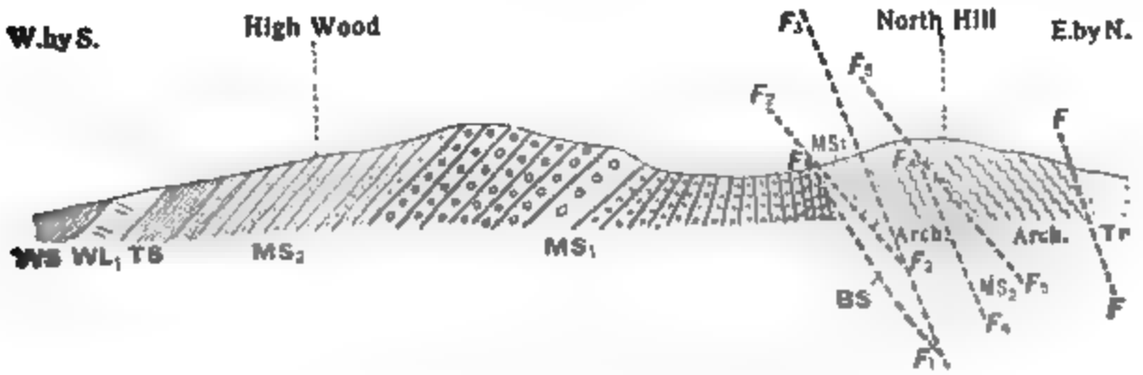

Fig. 49.—SECTION THROUGH HIGH WOOD NEAR WEST MALVERN (Professor Groom). Scale 6 inches to 1 mile.

Tr. Trias.
WS. Wenlock shale.
WL. Woolhope limestone.
TS. Tarannon shale.
MS_2. Upper, MS_1. Lower } May Hill sandstone.
BS. Black shales (Cambrian).
Arch. Pre-Cambrian.
FF. Faults.

of gray and purple colours about 600 feet thick, and yielding the usual fossils, together with *Ctenodonta Eastnori* and *Lingula crumena;* (2) an upper set of gray laminated sandstones and shales from 320 to 500 feet thick with *Pentamerus lens*, *P. undatus*, etc., the highest beds being shales which are doubtless equivalent to the Tarannon shales. The conglomerates rest unconformably upon the Cambrian shales where these are exposed, but do not, according to Professor

Groom, pass over them on to the older rocks, as formerly supposed, but are elsewhere faulted against the Pre-Cambrian rocks.

The Woolhope Limestone, with a thickness of from 20 to 50 feet, occurs at the base of the Wenlock series. The thickness of the Wenlock Shale was given as 640 feet by Phillips, but may be greater, and the Wenlock Limestone consists of several beds from 10 to 30 feet thick divided by shales, so that it includes some 200 to 280 feet of beds.

The Lower Ludlow and the Aymestry Limestone succeed, but the Upper Ludlows and Passage beds differ somewhat from those of Shropshire. They were traversed by the railway at Ledbury and described by Mr. W. S. Symonds, who recorded the following succession :—[11]

		Feet.
O.R.S.	Red marls and sandstones.	
Ledbury shales.	Gray marls and sandstones with fish remains and *Lingula cornea*	20
	Purple shales and sandstones with *Lingula*	34
	Gray shales and grit (*Cephalaspis*)	8
	Red and mottled beds with *Lingula* and *Pteraspis*	210
Yellow (Downton) sandstone		9
Upper Ludlow shales		140
Aymestry limestone (in the tunnel).		

The base of the Upper Llandovery is only exposed at one other locality, namely, in the small tract of the Lower Lickey Hill in Worcestershire, where it rests on the Cambrian quartzite. The May Hill and Woolhope inliers are periclinal domes, the centres of which are occupied by a certain thickness of May Hill beds, while the overlying beds dip outwards in every direction and the limestones form nearly continuous ridges or escarpments.

The following table shows the thickness in feet of the several subdivisions in the four principal districts :—

	Malvern.	May Hill.	Woolhope.	Stafford and Worcester.
Ledbury shales	272	?	?	
Downton sandstone	?9	70	80	
Upper Ludlow shale	140	100	180	Absent
Aymestry limestone	30	20	20	25
Lower Ludlow shale	700	440	660	800
Wenlock limestone	240	220	150	160
Wenlock shale	640	900	900	800
Woolhope limestone	50	60	50	40
May Hill sandstone Upper	400	200	270	?150
May Hill sandstone Lower	600	200	Not seen	

4. *North Wales*

It was stated on p. 148 that when the Shropshire Silurians are traced westward into Radnor and Montgomery the calcareous bands die out, the argillaceous beds increase in thickness, and arenaceous beds appear in all three portions of the series; and, further, that a lower group of Llandovery beds makes its appearance at the base. This Radnor facies still persists when the beds are followed northward from the valley of the Severn through Montgomery, Merioneth, and Denbighshire, and the general succession is as follows :—

			Feet.
Ludlow—Denbigh flags and grits	. .	About	4000
Wenlock—Moel Ferna beds	. . .	,,	1700
Valentian { Tarannon shale / Graptolitic mudstones / Corwen grits }	. .	,,	600 to 900

This succession as developed in the valley of the Dee is illustrated by the section, Fig. 50.

Valentian.—We prefer to use this name for the equivalents of the Llandovery beds in this and more northern districts because they present such a different facies from that of South and Central Wales. The equivalent of the Lower Llandovery appears to be persistent through North Wales, but it is of small thickness, and the Upper Llandovery is absent, or represented by beds which have been included in the Tarannon shale. Near Bala, and also at Corwen in the valley of the Dee, the Hirnant beds (Upper Bala) are succeeded by gray and white sandstones with bands of coarse and pebbly sandstone. The true position of these beds was first indicated by Professor Hughes in 1877,[12] and they are stated to be from 50 to 300 feet thick. Fossils are rare in them, but *Meristella crassa* and *Pentamerus oblongus* have been found. They pass up into soft bluish gray or black shaly mudstones which contain *Monograptus gregarius*, *Mon. tenuis*, and *Climacograptus normalis*, and these pass up into pale Tarannon slates, each of these divisions being about 300 feet thick.

The palæontological succession has been made out more fully near Conway by the Misses Elles and Wood,[13] as follows :—

Tarannon shales, alternating gray shales and flags containing *Monograptus exiguus*, *M. turriculatus*, *M. pandus*, and *M. runcinatus*.

Upper Llandovery, gray flags with thin layers of black shale, which contain graptolites, including *Diplograptus tamariscus*, *Climacograptus normalis*, *Monograptus gregarius*, *Rastrites peregrinus*, and *R. maximus*. The base is not seen.

Fig. 50.—SECTION THROUGH PART OF DENBIGHSHIRE SOUTH OF THE RIVER DEE (by P. Lake). Distance about five miles.

f. *Leintwardinensis* beds.
e. Upper gritty beds.
*d*¹. Nantglyn flags.
d. Moel Ferna slates.
c. Pen-y-glog grit.
b. Pen-y-glog slates.
a. Tarannon slates.

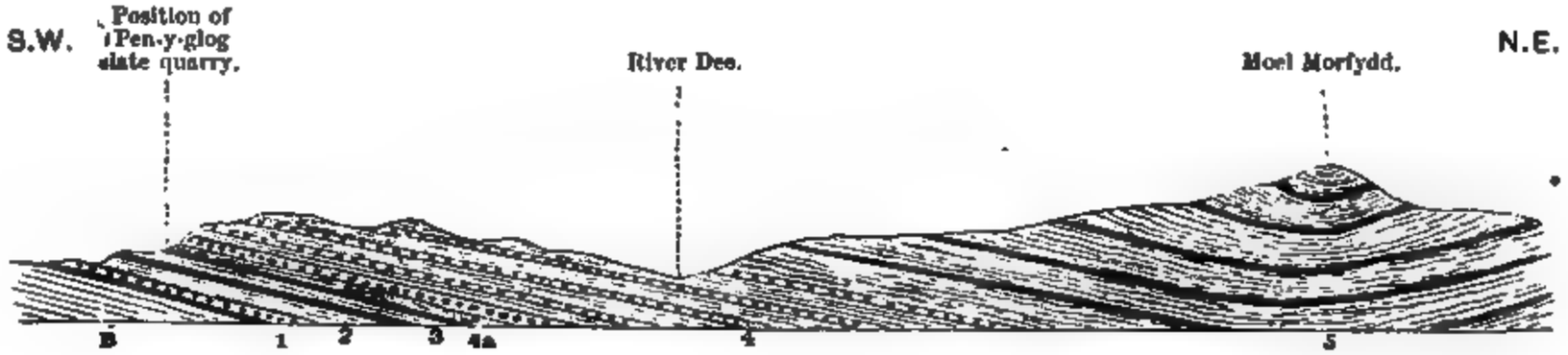

Fig. 51.—SECTION FROM NEAR CORWEN TO MOEL MORFYDD, DENBIGHSHIRE (Professor Hughes). Distance about six miles.
Vertical scale 3000 feet to 1 inch.

6. Llanrannan shales and Denbigh flags.
4. Denbigh grits.
4a. Zone of *Cyrtograptus Murchisoni*.
3. Tarannon shale.
2. Graptolitic mudstone.
1 Corwen grits.
B. Bala beds.

The authors remark that the part of the Tarannon Shales exposed may be correlated with the Lower Gala beds of Scotland, and that the upper zone of *Monograptus Grayæ* is absent or concealed by an overlap of the Wenlock shales.

Wenlock and Ludlow Series.—The most accurate and detailed information on the representatives of these beds in Denbighshire is found in the paper by Mr. Philip Lake on South Denbigh,[14] those by Professor Hughes on the Silurians of the valley of the Clywd,[15] and in notes by Miss Elles and Miss Wood.[16] Combining the observations and correlations of these authors, we find that the succession may be generalised as follows :—

Ludlow series, ? 4000 feet	6. Gritty sandstones and wavy banded concretionary mudstones of Moel Ganol. 5. Gray banded mudstones and sandstones with *Acidaspis Hughesi*. 4. Nantglyn flags with "*Actinocrinus pulcher*," *Rhynchonella nucula*, *Dayia navicula*, *Orthoceras Sedgwicki*, *O. primævum*, *Cardiola interrupta*, and *Monograptus Nilssoni*.
Wenlock series, ? 1700 feet	3. Moel Ferna slates with *Monograptus priodon* and *M. Flemingi*. 2. Pen-y-glog grit with *Meristella tumida*, *Strophomena depressa*, *Phacops sp.*, and Encrinites. 1. Pen-y-glog slates with *Cyrtograptus Murchisoni*, *Retiolites geinitzianus*, *Monograptus priodon*, and *M. vomerinus*.

The slates at the base are the equivalents of the lower part of the Wenlock Shales, and the same fossils have been found in beds overlying the Tarannon Shales near Conway. The Moel Ferna beds must include the representative of the Wenlock Limestone, but they yield very few fossils. The Nantglyn flags represent the Lower Ludlow beds, and Miss Elles has recognised two zones in them, a lower zone of *Monograptus vulgaris* and a higher one of *M. Nilssoni*. In the valley of the Dee Mr. Lake found some micaceous flagstones which contain *Monograptus leintwardensis* in abundance, and these cannot be far below the horizon of the Aymestry Limestone. This zone is probably to be found in the banded beds (No. 5) of the Clywd valley section, but has not yet been detected there. In South Denbigh the highest beds occur at Dinas Bran near Llangollen, and have yielded *Orthoceras Sedgwicki*, *Cucullela coarctata*, *Dayia navicula*, *Chonetes minima*, and other fossils.

The series is incomplete owing to the unconformable superposition of the Carboniferous rocks, but it probably included still higher beds comparable to those of Westmoreland, for fragments of such beds occur as pebbles in the basement conglomerates of the Carboniferous system.

5. *Westmoreland*

The Silurian sequence in the north of England does not differ greatly from that of North Wales, but it is much more complete, has been more fully investigated, and the beds are also rather more fossiliferous, so that they are more easily subdivided. For a long time the correlation of the Westmoreland groups with those of Shropshire and Radnor was very uncertain, but the recent studies of graptolites by Messrs. Marr and Nicholson and by Miss G. Elles have placed the comparison on a sounder basis.

The Westmoreland succession was first examined and described by Professor Sedgwick ; it was subsequently mapped by the officers of the Geological Survey, and has been studied by Mr. Marr and others. The following is the classification which embodies the results of all these workers.

Valentian.—Where the sections are most complete, as in Stockdale and at Spengill, there are no arenaceous beds of the Llandovery type, but a series of shaly mudstones resting directly on the Ashgill Shales with apparent conformity. In some parts of the area, however, the lowest shales are replaced by a few feet of gritty conglomerate. The ordinary facies is known as the Stockdale Shales ; its total thickness is not more than 250 feet, and it is divided into two subgroups : (1) the Skelgill Beds ; (2) the Browgill Beds.[17] By the Geological Survey the groups are called (1) the Graptolitic mudstones and (2) the Pale slates.

The Skelgill Beds have a thickness of 70 or 75 feet, and have at the base a thin limestone containing *Atrypa flexuosa*, succeeded by shale with *Dimorphograptus confertus*. The middle beds contain *Monograptus gregarius* and *Rastrites peregrinus*, with *Encrinurus punctatus* and *Phacops glaber*. The higher beds yield *Monograptus spinigerus* and *M. Clingani*, with many trilobites, and in the Spengill section there is a still higher band containing *Rastrites maximus* in abundance.

The Browgill Beds are thicker (about 140 feet) but less fossiliferous. They are divisible into three parts : (1) a zone of *Monograptus turriculatus ;* (2) a zone of *M. crispus ;* (3) barren shales and grits.

Wenlock Series.—The beds referable to this stage consist almost entirely of flagstones, shaly in the lower part, gritty above. They are thus divisible into two groups :—

i. *The Brathay Flags* are bluish laminated flags of fine grain about 1000 feet thick, and are comparable with the Wenlock Shale. They contain *Cyrtograptus Murchisoni*, *Monograptus priodon*, and *M. vomerinus.*

ii. *The Coldwell Grits.*—These are part of Mr. Marr's "Coldwell Beds," [18] but as there now seems little doubt that the lower part of these beds is Salopian, and that the higher part is of Ludlow age, it will be convenient to speak of the lower group as the Coldwell grits, and of the higher group as the Coldwell flags. The lowest beds are coarse gray grits, and are probably equivalent to the zone of *Cyrtograptus Lundgreni* (see p. 138). The "Middle Coldwell Beds" are flaggy calcareous grits, and contain many species of *Orthoceras* with *Cardiola interrupta* and *Phacops obtusicaudatus*, but have not yielded any graptolites, so that their exact position is somewhat doubtful; but we may regard them as probably of Wenlock age. The total thickness of the Coldwell grits is about 1500 feet.

Ludlow Series.—This series is of enormous thickness in Westmoreland, and is divisible into four separate stages or groups.

i. *The Coldwell Flags* (or Upper Coldwell Beds) are gray gritty flags from 1000 to 2000 feet thick. They have yielded *Monograptus colonus* and *M. Rœmeri* with *Acidaspis Hughesi*, *Phacops Stokesi*, *Actinocrinus pulcher*, *Pterinœa tenuistriata*, and *Tentaculites tenuis*, and are clearly of Lower Ludlow age.

ii. *The Coniston Grits.*—These represent the upper grits of Wales, and are about 4000 feet thick. Fossils are rare, but *Cardiola interrupta*, *Pterinœa tenuistriata*, and *Orthoceras subundulatum* occur, and near Sedbergh there is a band of coarse grit, about 1200 feet from the base, which contains *Dayia navicula*, *Chonetes lata*, and *Orthis lunata*, these being Ludlow species, and reappearing later on in the higher beds of the same area.

iii. *Bannisdale Slates.*—These beds have a total thickness of about 5000 feet. The lower portion consists of sandy mudstones with thin beds of hard sandstone. Fossils are rare, but the presence of *Monograptus leintwardinensis* throughout indicates that they represent the higher part of the Lower Ludlow shales. Other fossils are *Orthoceras primævum*, *O. subundulatum*, and a variety of *Calymene Blumenbachi* have been found. The higher beds consist of bluish thin-bedded sandstones with subordinate beds of shale, containing *Protaster Miltoni*, *Dayia navicula*, *Cucullella Cawdori*, *Phacops Downingiæ*, and other fossils. There is also a calcareous band which contains *Palæaster*, *Proëtus latifrons*, and *Dayia navicula*, and has been identified by Mr. Aveline with the Aymestry limestone. These beds are about 1200 feet thick.

iv. *The Kirkby Moor Flags* are massive greenish and gray sandstones, with calcareous (fossiliferous) bands, passing up into thin-bedded flags. This group is more than 2000 feet in thickness. Fossils are abundant, the following being some of the most characteristic :—

Lingula cornea.	Grammysia cingulata.
Discina rugata.	Cyclonema corallii.
Spirifera elevata.	Holopella gregaria.
Chonetes lata.	Orthoceras ludense.
Orthonota amygdalina.	Lituites ibex.

6. *South of Scotland*

The Silurian succession in this region was first deciphered by Professor Lapworth,[19] who described the two special facies exhibited by the rocks of Valentian age near Moffat in Dumfries and near Girvan in Ayrshire. More recently the whole region of the southern uplands has been described in detail by Messrs. Peach and Horne.[20] The Silurian rocks occupy the southern half of the upland region in a broad belt from 20 to 30 miles in width, and extending from the Berwick coast on the east to that of Wigtown on the west. On the northern side they occur as isolated exposures in Ayrshire, in Lanark, and in the Pentland Hills.

Valentian.—In Dumfries and the central belt the lowest beds are soft black shales, known as the Birkhill Shales; they lie conformably upon the Hartfell Shales (Bala), are equivalent to the Skelgill Shales of Westmoreland, and are of about the same thickness (140 feet). (See Figs. 35 and 36, p. 119.) They are rich in graptolites, and are divisible into the following zones :—

Upper Birkhill	Zone of Rastrites maximus.
	,, ,, Monograptus spinigerus.
	,, ,, Petalograptus cometa.
Lower Birkhill	,, ,, Monograptus gregarius.
	,, ,, Diplograptus venculosus.
	,, ,, Diplograptus acuminatus.

These shales are succeeded by a thick series of sediments, from 3000 to 4000 feet, which are called the Gala group by Professor Lapworth, and have been divided by the Survey into the following :—

3. Hawick beds. Shales, flags, etc., few fossils.
2. Queensberry grits. Massive grits with some layers of shale but few fossils.
1. Abbotsford flags. Flags and shales with *Monograptus turriculatus*, *M. crispus*, *M. exiguus*, etc.

In the Girvan area the Birkhill shale is represented by a much thicker series of a Llandovery type, the lower beds containing Lower Llandovery fossils and the upper beds including a limestone with many fossils, such as *Pentamerus oblongus*, *Stricklandia lens*, *Illænus æmulus*, and *Phacops Stokesi*. Above this, and representing the Gala group, are the Penkill beds, with a thickness of 1000

feet, the topmost of these being mudstones containing *Cyrtograptus Grayæ*.

Salopian.—In the main belt the Gala group is succeeded by the Riccarton Beds, a series of conglomerates, grits, mudstones, and shales from 1000 to 1500 feet thick, and containing *Cyrtograptus Murchisoni*, *Monograptus vomerinus*, and *M. priodon*. At Raeberry near Kirkcudbright there are still higher beds, consisting of green marls with limestone nodules, which are either highest Wenlock or possibly of Ludlow age.

In the Girvan area the representatives of the Wenlock Beds consist largely of unfossiliferous flagstones, and only the lower part of the series is exposed. This is divided into two groups by Professor Lapworth. The lower or Bargany group consists of fine thin bedded flagstones with interstratified shales, and has a thickness of about 700 feet, the only fossils being the graptolites *Monograptus acus* and *M. priodon*. The higher group he called the Straiton Beds, at the base of which are olive-green flags well seen at Drumyork, succeeded by shales containing *Monograptus vomerinus*, *Cardiola fibrosa*, *Orthonota truncata*, and other fossils. The highest beds seen are purplish grits and conglomerates which pass beneath Carboniferous sandstones, the exposed thickness of the Straiton group being about 900 feet.

The highest beds referable to the Wenlock series are well exposed in Lanark, where they are no less than 2200 feet thick (see table below), and yet do not include any beds comparable to those near Straiton ; hence there seems to be a gap in the succession, and the full thickness of this series in Scotland is not yet known.

Ludlow Series.—These beds are not found in the main belt nor in the Girvan district, but only in Lanark and the Pentland Hills, where the following succession has been recognised :—

		Feet.
Downton and Ludlow Beds	Chocolate coloured sandstones . . .	2700
	Conglomerate with quartz pebbles . . .	
	Mudstones and shales with fish and eurypterids	
	Red and yellow sandstones and mudstones .	
	Red and green shales with *Platyceras simulans*	1480
Wenlock Beds	Brown sandstones with *Orthoceras* . . .	2200
	Green and gray shales and mudstones . .	
	Massive sandstones and grits	
	Green, red, and purple shales with eurypterids	
	Starfish, crinoids, and corals	

The beds which are bracketed as having a thickness of 2700 feet were formerly grouped with the Old Red Sandstone, but are regarded by the Geological Survey as the equivalents of the Downton and Ledbury beds. They include a band of shales which has yielded many remains of fish and Merostomata. The fish fauna is of great

interest, as two of the genera belong to a family which has hitherto been known only from scales; these genera are *Thelodus* and *Lanarkia*, belonging to the family *Cœlolepidæ*, which, according to Dr. Traquair, are nearly related to the *Pteraspidæ*, although they have superficial resemblances to the sharks. Other new genera found in these beds are *Ateleaspis*, *Birkenia*, and *Lasanius*. The Merostomata include species of *Stylonurus* and *Eurypterus*, and the Crustacean *Ceratiocaris* is also present. The underlying Ludlow shales have yielded the earliest British arachnid in the form of a scorpion (*Palæophonus*), a genus first described from remains in the Silurian of Gottland (Sweden).

7. *Ireland*

Rocks of Silurian age succeed the Ordovician series in many parts of Ireland; they may be described as exhibiting two different facies, the one comparable with the Scotch type and the other with the Llandovery-Wenlock type.

Eastern Facies.—Valentian rocks of the Birkhill-Gala type occur in the north-eastern and central counties, and probably they extend under the whole of Central Ireland down to the coast of Waterford. Rocks having the same general character as the Birkhill shales and Gala series of Southern Scotland range through the counties of Down, Armagh, Monaghan, and Cavan; it has in fact been found that the greater part of the tract which was coloured as "Lower Silurian" on the older geological maps of Ireland consists of Valentian rocks.[21] The older beds (Birkhill shales) occur chiefly along the north-west border of the area, and have yielded the characteristic graptolites, *Diplograptus folium*, *Monograptus gregarius*, *M. Sedgwicki*, and *Rastrites maximus*. South of this zone are rocks of Gala type containing *Monograptus priodon*, *M. turriculatus*, and *M. riccartonensis*, while in County Louth there are rocks comparable to the Riccarton group with Wenlock fossils.

Graptolitic Valentian beds have also been found near Pomeroy in Tyrone, and again far to the south-west in Clare, Tipperary, and Waterford, where large inliers of Silurian and Ordovician rocks are brought up by anticlinal domes from beneath the Old Red Sandstones.

Western Facies.—In the district lying between Lough Mask and Killary Harbour (County Mayo), and again in the Dingle promontory of Kerry, there are thick developments of the whole Silurian system, and here the deposits give evidence of the close proximity of land.

In Mayo the lowest beds are conglomerates, sandstones, and

shales, the conglomerates containing pebbles of the Pre-Cambrian schists and quartzites, which lie to the southward in Connemara, while the finer beds have yielded *Atrypa hemispherica*, *Illænus Bowmanni*, *Encrinurus punctatus*, and other fossils. These beds are overlain by sandstones and shales containing Wenlock fossils, and these are succeeded by the Salrock beds, red shales with red and green grits, some of which are full of small *Lingulæ* (*L. Symondsi*), with *Pterinæa retroflexa* and *Trochus multitorquatus*, and may be of Ludlow age.

In the Dingle promontory the ascending succession is as follows :[22]—

(1) Smerwick beds, a thick series of red, green, and yellow sandstones with bands of conglomerate ; fossils rare, but *Atrypa hemispherica* and others have been found at certain localities.

(2) Ferriters Cove beds, greenish sands and shales with bands of red sandstone ; these beds are 2500 feet thick and contain fossils of Wenlock species.

(3) Croaghmarhin beds, hard brown calcareous grits with *Pentamerus Knighti* and other Ludlow fossils. These dip southward at a high angle and pass below a great series of green and purple grits and shales, which are known as the Glengariff grits, and believed to be of Devonian age. See Fig. 62, p. 193.

Contemporaneous Volcanic Rocks

The only district in England where volcanic rocks are associated with Silurian strata is that of Tortworth in Gloucestershire. Though the existence of igneous rocks had long been known, it is only quite recently that they have been carefully examined and proof obtained of their being really contemporaneous with the beds in which they occur. Professors Lloyd Morgan and H. S. Reynolds[23] have shown that there are two sheets of basaltic andesite ; the lower sheet underlies rocks with Upper Llandovery fossils, and the upper sheet appears to lie between the Llandovery and a limestone of Wenlock age, and both have associated ash beds.

The only other tract in the British Isles where evidences of Silurian vulcanicity are known to occur is in Ireland in the Dingle promontory of Kerry. The best sections are in the cliffs near Clogher Head, where the interstratification of the lavas and tuffs with the fossiliferous Wenlock beds is beautifully exposed. Sir A. Geikie describes the lavas as nodular felsites, the nodules being from the size of a pea to that of a hen's egg, and the associated pyroclastic rocks vary from fine pumiceous tuffs to coarse agglomer-

ates. One of these beds is a coarse agglomerate about 15 feet thick, consisting of large blocks of felsite embedded in calcareous sandstone which is full of the casts of brachiopods, crinoids, and corals. The district has been recently examined by Messrs. S. H. Reynolds and C. T. Gardiner, who kindly inform me that some of the lavas are rhyolites, and that all are of acidic character.

From these facts we learn that a volcano existed in this part of the Silurian sea, and that from time to time it burst into eruption, pouring forth lava streams and ejecting showers of stones and ashes, which fell into the surrounding sea and were spread out on its floor, while between each epoch of eruption marine sediments of the usual kind were greatly accumulated.

Continental Equivalents

Rocks of Silurian age occur in Scandinavia, Russia, Bohemia, Thuringia, Carinthia, Belgium, north-west of France, the Pyrenees, and Spain. We shall only refer briefly to those in Scandinavia, Russia, Bohemia, and France.

Scandinavia.—The Silurian series of Scandinavia has been compared with those of Britain by Mr. J. E. Marr,[24] and the following account is taken chiefly from his description. The principal districts in which the rocks occur are Christiania, Scania, Dalecarlia, Westrogothia, and Ostrogothia. It may be mentioned that the total thickness of the series in Scania (some 5000 feet) is much greater than the Scandinavian Silurians were formerly credited with. In the other districts it is less than 1000.

The basement beds, as pointed out by Mr. Marr, do not always rest on the same member of the Ordovician system, so that there are local unconformities in Sweden as in Britain. At the base there is sometimes a conglomerate (as near Christiania), but in Sweden the base is a calcareous grit or gritty limestone overlain by shales containing *Mon. lobiferus*, which contain Llandovery trilobites and brachiopods with some graptolites, thus exhibiting a kind of intermediate facies between our Llandovery and Birkhill types.

The Lobiferus beds are succeeded by the Retiolites (or *Cyrtograptus*) shales, which correspond with our Wenlock shales, and present a succession of graptolite zones that closely correspond with those established by Miss Elles at Ludlow and Builth, the highest being the zone of *Cyrtograptus Lundgreni*, and therefore probably the equivalent of our Wenlock limestone.

The *Cardiola* shales, which consist of shales with lenticular beds of limestone and are 3000 feet thick, must represent our Lower Ludlow, for they contain the characteristic graptolites *Monograptus scanicus*, *M. Nilssoni*, *M. colonus* and *M. bohemicus*. At the top is

a fossiliferous limestone with *Homalonotus*, corals, and brachiopods, which seems to be homotaxial with our Aymestry limestone, and still higher is a sandstone that is comparable with the Downton beds.

Thus in Scania the important sequence of Cambrian and Ordovician rocks (see pp. 91 and 124) is continued as follows :—

		Feet.
Downton and Ludlow	Yellow sandstone of Kaerrstorp	800
	Green shales and limestone	400
	Cardiola shales	3000
Wenlock	= Cyrtograptus shales	600
Llandovery	Lobiferus beds (with graptolites)	? 200
	Thin gritty limestone	

The Isle of Gottland is wholly composed of Silurian strata, consisting chiefly of limestones, oolite, and marls full of fossils. The base is not seen, but the beds, exposed, although only about 200 feet thick, include representatives of the Llandovery, Wenlock, and Ludlow series.

Russia.—In the Baltic provinces of Russia the whole system is similarly reduced to a thickness of less than 300 feet, and yet all three stages are represented. The beds consist of soft horizontal and unaltered strata, chiefly marls and limestones, the general aspect of which is like that of our Secondary rocks.

Bohemia.—In this region the Silurians have a greater thickness (2000 to 3000 feet), and present a complete sequence of highly fossiliferous rocks. They were made famous by the laborious researches of Barrande, and his subdivisions have been correlated with the British sequence by Mr. Marr, to whose paper the reader is referred.[25]

France.—Silurian rocks occur in Normandy, Brittany, and Languedoc, and the following account of the succession found in Brittany is taken from that by Professor Barrois.[26] He notes that in this area the Silurian has the character of a carbonaceous slate formation, that brachiopods and trilobites are seldom found, but that graptolites are abundant and that cherts with radiolaria also occur. It is clearly a deep-water facies of the Silurian, just as the Moffat series is a deep-water facies of the Ordovician. The highest beds are absent by erosion, and the following is the succession found in descending order :—

Salopian.
5. *Cardiola slates.*—Poor in fossils except where there are layers of calcareo-siliceous nodules containing *Orthoceras styloideum*, *Cardiola interrupta*, and other Lamellibranchs.
4. *Slates of Menardais* with *Retiolites geinitzianus*, *Monograptus vomerinus*, *M. riccartonensis.*

Valentian.
3. *Ampelites of Poligné* with *Mon. spiralis* and *Cephalograptus folium.*
2. *Phtanites of Anjou*, laminated chert beds with radiolaria and graptolites (*Rastrites* and *Mon. lobiferus*).
1. Fine sandstones and shales without fossils.

Physical and Geographical Conditions

We have seen that in some districts the Silurian deposits succeeded the Ordovician without any break or sign of disturbance, while in others great disturbance and upheaval took place at the commencement of the period, followed by renewed subsidence, during which the materials gained from the land tracts were quietly spread over the sea-floor, and that finally a general incoming of sandstones indicates a general elevation of the whole British region and a narrowing of the areas of deposition.

Let us first glance at the testimony afforded by the characters of the sediments in different places during Valentian and Wenlock times in respect to the relative depth of water and distance from land. Thus we find that deep-water deposits occur in Brittany, over Central and Eastern Ireland, and in the extreme south of Scotland. On the other hand, conglomerates and sandstones indicative of shallow water and of the nearness of land occur in Wales and Central England, in the north-west of Ireland, and in Ayrshire.

No Silurian rocks emerge from beneath the Old Red Sandstone of Central or Northern Scotland, and this absence, taken in connection with the fact that the final plication and metamorphism of the older Palæozoic rocks of the Highlands dates from before the epoch of the Old Red Sandstone and after that of the Arenig, makes it highly probable that this great terrestrial disturbance was accomplished either just before or during the course of the Silurian period; this conclusion finds confirmation in the structure of the north-west of Ireland.

The outcome of these disturbances seems to have been the elevation of a large mass of continental land over the region of the north Atlantic, and the formation of a series of mountain ranges which had a general trend from south-west to north-east, the borders of this land running through the north-west of Ireland, the central highlands of Scotland, and thence across the North Sea into Norway.

The conglomerates and other Valentian rocks in Ayrshire were probably formed off a part of this land, either against the shore of a promontory projecting from it, or round a set of islands not far from the main coast-line.

Farther south, over Central England and the Welsh borders, was an island of some size. We have seen that the Ordovician period closed with a fresh upheaval of land in this area, and that for a portion of Llandovery time this land yielded much detritus, which was spread out round its western shores in the form of the

deposits which we call the Lower Llandovery. During Upper Llandovery time this land slowly sank again and was covered by Silurian sediments.

There remains only to consider whence came the great quantity of sand which forms the chief constituent of the Wenlock and Ludlow rocks of North Wales, Westmoreland, and Southern Scotland. The total thickness of these rocks in Westmoreland is 14,500 feet, and though there is no district in Scotland where the succession is complete, the series there may originally have been equally thick. In North Wales there is 5700 feet without a top. Some of the material may have come from the land to the north, but Westmoreland is 130 miles south of the Central Highlands, and North Wales is about 200 miles away, which seems a great distance for coarse sand to be carried.

It is difficult to see where this 14,500 feet of sediment could have been brought from, unless it came from an easterly direction. It is possible that the land which existed over Central England in Llandovery time was only the south-western extremity of a larger and higher mass of land which occupied a position in what is now the North Sea, and that, though the promontory was submerged in Wenlock times, the mainland remained above the sea throughout the whole period and rose into lofty ridges, whence was swept down the sand and silt that was piled up to such a thickness in Westmoreland.

Silurian rocks of Westmoreland type are exposed in the upper part of Ribblesdale in West Yorkshire, but we have no knowledge at present as to their farther eastward extension. The only other facts which tend to confirm the above supposition are that the general trend of the supposed land is parallel to that of the north-western land, and that further uplifts having the same general trend took place in the succeeding period of the Old Red Sandstone.

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[3] See Miss Wood's paper on the Lower Ludlow beds, *Quart. Journ. Geol. Soc.* vol. lvi. p. 415, 1900.

[4] See H. Lapworth, *Quart. Journ. Geol. Soc.* vol. lvi. p. 67.

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[6] Miss Elles in *Quart. Journ. Geol. Soc.* vol. liv. p. 463 (1898).

[7] Miss Wood, *Quart. Journ. Geol. Soc.* vol. lvi. p. 415 (1900).

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[9] See Marr and Roberts, *Quart. Journ. Geol. Soc.* vol. xli. p. 476.

[10] *Quart. Journ. Geol. Soc.* vol. xxxv. p. 475.

[11] W. S. Symonds in *Quart. Journ. Geol. Soc.* vol. xvi. p. 193.

[12] *Quart. Journ. Geol. Soc.* vol. xxxiii. p. 207 ; see also T. Ruddy in *Quart. Journ. Geol. Soc.* vol. xxxv. p. 207, and J. E. Marr, vol. xxxvi. p. 277.

[13] *Quart. Journ. Geol. Soc.* vol. lii. p. 273.

[14] *Ibid.* vol. li. p. 9.

[15] *Ibid.* vol. xxxvii. p. 482, and *Proc. Chester Soc. N. H. and Lit. for 1885 and 1893.*

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[17] See Marr and Nicholson in *Quart. Journ. Geol. Soc.* vol. xliv. p. 658.

[18] *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 871 (1878), and *Geol. Mag.* Dec. 3, vol. ix. p. 534.

[19] Professor Lapworth in *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 240, and vol. xxxviii. p. 537.

[20] "Geology of the Southern Uplands of Scotland," *Mem. Geol. Survey*, 1900.

[21] See *Summaries of Progress of Geol. Survey for 1897 and 1898.*

[22] See *Explanations of the Maps 160, 161, 171 of the Geological Survey of Ireland.*

[23] *Quart. Journ. Geol. Soc.* vol. lvii. p. 267 (1901).

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CHAPTER X

DEVONIAN AND OLD RED SANDSTONE SYSTEM

General Classification and Subdivisions

WE have seen in the last chapter that, where complete sections are found, the Silurian rocks pass upwards into a thick series of red sandstones (England and Scotland), or into an equally thick series of gray and purple grits (Ireland). It will be shown in a future chapter that the marine carboniferous rocks always rest upon a set of red and yellow sandstones, which often repose unconformably upon some of the more ancient Palæozoic strata. The marine fauna of the Silurian dies out at the base of the red sandstones, and when we reach the next marine fauna—that of the Carboniferous system—it is totally different from the preceding, so that a long period of time must have elapsed between the close of the Silurian era and the commencement of the Carboniferous.

The groups known as the Old Red Sandstone in England and Scotland, and the Glengariff grits or Dingle beds in Ireland, are clearly some of the rocks which were formed in this interval; and if these were the only records of this portion of geological time, we might find it convenient to regard the whole of the beds which succeed the Silurian series in conformable sequence as belonging to the Silurian system.

But these are not the only strata which are interposed between the Silurian and Carboniferous systems. In Devonshire, and in many localities in Europe, there is a thick series of rocks containing a marine fauna which is evidently of intermediate age; further, in Germany the stratigraphical proof of their interposition between Silurian and Carboniferous rocks is complete. It is this marine series which must be taken as the normal type of the intermediate system, and any freshwater deposits which can be shown to be of the same age must be treated as local contemporaneous or homotaxial

strata. In America also both types of the Devonian system are present.

The Devonian system was established by Sedgwick and Murchison in 1839 because they found in Devon a great series of rocks containing a special assemblage of fossils, and they divided this Devonian system into Lower, Middle, and Upper groups; the convenience of this division has been confirmed by the researches of continental geologists.

The Old Red Sandstone, which elsewhere occupies the position of the Devonian system, is believed to be of lacustrine or estuarine origin. It has been divided into a lower and upper series, with a middle series in Wales, but in Scotland there is a marked unconformity between the upper and lower series, and it is doubtful whether the upper series is really of Devonian age. It is probable that the Lower Old Red Sandstone may be correlated with the Lower Devonian, that the Middle Devonian was formed during the time represented by the unconformity in Scotland and Ireland, but whether any part of the Upper Old Red Sandstone is really of Devonian age will depend very largely on the results of further researches in North Devon.

The student will understand that the rocks belonging to this system require further investigation, and that our nomenclature stands in need of alteration; the cumbrous designation of Old Red Sandstone should be relinquished, and a new name should be found for the estuarine Devonians, while it must be ascertained how much of the Upper Old Red Sandstone can be correlated with the Upper Devonian of Devon.

A Devonian Life

In Britain the only surface exposures of marine Devonian rocks occur in Devon, Somerset, and Cornwall; they occupy the northern parts of Devon and Somerset between Morte Bay and the valley of the Tove, as well as the outlying tract of the Quantock Hills, east of that valley. Dipping southward beneath the central Carboniferous area, they reappear in South Devon and North Cornwall.

The strike of these rocks is nearly due east and west, and this appears to be maintained in their subterranean extension through the south of England, for rocks with the same Devonian fossils have been met with in borings beneath the Cretaceous beds which underlie London and Essex. They are known to occur in the same position in Belgium, and they emerge again to the surface in the Ardennes, so there is every probability of their being continuous across the intermediate areas.

Life of the Period

As already mentioned, the Devonian fauna is intermediate in character between those of the Silurian and Carboniferous. Most of the characteristic Silurian genera become extinct in the Lower and Middle Devonian, while in the Middle and the Upper Devonian many genera which are prominent members of the Carboniferous fauna make their appearance. This is especially the case with the brachiopods, for all the Lower Devonian genera are found in the Silurian, while all those in the Upper Devonian range into the Carboniferous.

The following is a brief account of the principal genera which survive from the Silurian period, and of the more important genera which make their first appearance in Devonian rocks.

Among **Actinozoa**, *Acervularia*, *Alveolites*, *Cyathophyllum*, *Cystiphyllum*, *Favosites*, *Heliolites*, *Strombodes*, *Plasmopora*, and *Syringopora* continue from the Silurian, and Zaphrentoid corals, which are rare in the Silurian, now become abundant. *Calceola*, *Heliophyllum*, and *Pleurodictyum* occur only in Devonian rocks. *Michelinia*, *Zaphrentis*, and *Phillipsastrea* appear and range into the Carboniferous.

Among **Hydrozoa** the Stromatoporoids, which had some representatives in Silurian time, become specially abundant, and are characteristic of Devonian limestones. The principal genera are *Stromatopora*, *Actinostroma*, and *Hermatostroma*.

Among **Echinoderma** the Crinoids *Cyathocrinus*, *Ichthyocrinus*, *Rhodocrinus*, and *Taxocrinus* continue. *Dorycrinus*, *Cupressocrinus*, *Hexacrinus*, *Melocrinus*, *Sphærocrinus*, and *Rhipidocrinus* are specially Devonian genera. *Poteriocrinus* and *Haplocrinus* appear and survive. Of *Echinoids* certain archaic forms occur, such as *Lepidocentrus*, which has from five to eleven rows of interambulacral plates.

Among **Crustacea**, trilobites are on the decline, though individuals are sometimes common. Representatives of ten genera have been found in British Devonian rocks, *Acidaspis*, *Bronteus*, *Cheirurus*, *Cyphaspis*, *Lichas*, *Harpes*, *Homalonotus*, *Phacops*, *Proetus*, and *Dechenella*. Of these *Phacops*, *Proetus*, *Bronteus*, and *Cyphaspis* are the commonest. The Ostracods *Beyrichia* and *Entomis* are also common.

Of **Brachiopoda** many of the Silurian genera survive and many new forms make their appearance; of the latter *Cyrtina*, *Centronella*, *Davidsonia*, *Rensselæria*, *Meganteris*, *Stringocephalus*, and *Uncites* are only known in Britain as Devonian fossils, while *Camarophoria*, *Productus*, *Strophalosia*, and *Terebratula* (*Dielasma*) range into the Carboniferous.

Of **Lamellibranchia** the following Silurian genera occur, but those with an asterisk die out within the period: *Ambonychia*,* *Myalina*, *Grammysia*,* *Leptodomus*, *Ctenodonta*, *Cardiola*,* *Cleidophorus*,* *Conocardium*, *Cyrtodonta*.* *Pterinea* is very abundant, and the sub-genus with elongate wings (*Actinodesma*) is specially characteristic. The following genera appear and range into higher strata: *Avicula*, *Aviculopecten*, *Cucullæa*, *Parallelodon*, *Nucula*, *Pleurophorus*, *Edmondia*, *Prothyris*, *Megalodon*, *Curtonotus*, *Myophoria* (?), and *Solenopsis*.

Among **Gastropoda** the following genera survive and have many Devonian species: *Murchisonia*, *Pleurotomaria*, *Euomphalus*, *Straparollus*, *Capulus*, *Loxonema*, *Macrochilina*, and *Bellerophon*. Besides these *Cyclonema*, *Callonema*, *Eunema*, and *Holopella* occur, but die out within the period. *Scoliostoma* and *Philoxene* are Devonian only; *Naticopsis* and *Porcellia* appear and range upward.

Among **Cephalopoda** the following continue: *Orthoceras*, *Cyrtoceras*, *Gyroceras*, *Poterioceras*, *Gomphoceras*, *Trochoceras*, and *Phragmoceras*. The two last genera become extinct. *Clymenia* and *Bactrites* are specially Devonian, and the Goniatitidæ make their first appearance with the following genera: *Mimoceras*, *Anarcestes*, *Agoniatites*, *Gephyroceras*, *Tornoceras*, *Mœneceras*, *Brancoceras*, *Beloceras*, and *Prolecanites*.

Of **Pisces**, *Pteraspis* and *Scaphaspis* occur in the Lower Devonian.

The following are some of the most characteristic fossils of each division as found in England, France, and Belgium.

Fossils of the Lower Devonian

Actinozoa. Pleurodictyum problematicum, Zaphrentis oolitica.
Echinoderma. Cyathocrinus megastylus.
Brachiopoda. Spirifer primævus, S. paradoxicus, S. hystericus, S. lævicosta, Orthis arcuata, Chonetes dilatata, C. sarcinulata, Rensellæria crassicosta, Leptæna laticosta, Rhynchonella daleidensis.
Lamellibranchia. Avicula anisota, A. spinosa, Pterinea (Kochia) capuliformis, Ctenodonta Krachtæ.
Crustacea. Homalonotus armatus, H. Champernowni, H. gigas.

Fossils of the Middle Devonian

Hydrozoa. Stromatopora concentrica, S. placenta.
Actinozoa. Acervularia pentagona, A. Goldfussi, Favosites (Pachypora) polymorpha (cervicornis), Cyathophyllum damnoniense, C. cæspitosum, Cystiphyllum vesiculosum, Alveolites suborbicularis, Calceola sandalina, Heliolites porosus.
Echinoderma. Sphærocrinus geometricus, Hexacrinus interscapularis.
Crustacea. Proetus batillus, Bronteus granulatus, Cyphaspis ocellata.

Brachiopoda. Atrypa reticulata, A. desquamata, Stringocephalus Burtini, Pentamerus brevirostris, Meristella plebeia, Uncites gryphus, Streptorhynchus umbraculum, Rhynchonella acuminata, R. cuboides, Cyrtina heteroclita.

Lamellibranchia. Megalodon cucullatum, Conocardium clathratum, Cypricardinia scalaris, Pterinea placida, Rutotia elliptica.

Gastropoda, etc. Loxonema reticulatum, Macrochilina imbricata, Murchisonia turbinata (and var. angulata), Pleurotomaria delphinuloides, Philoxene lævis, P. serpens, Porcellia bifida.

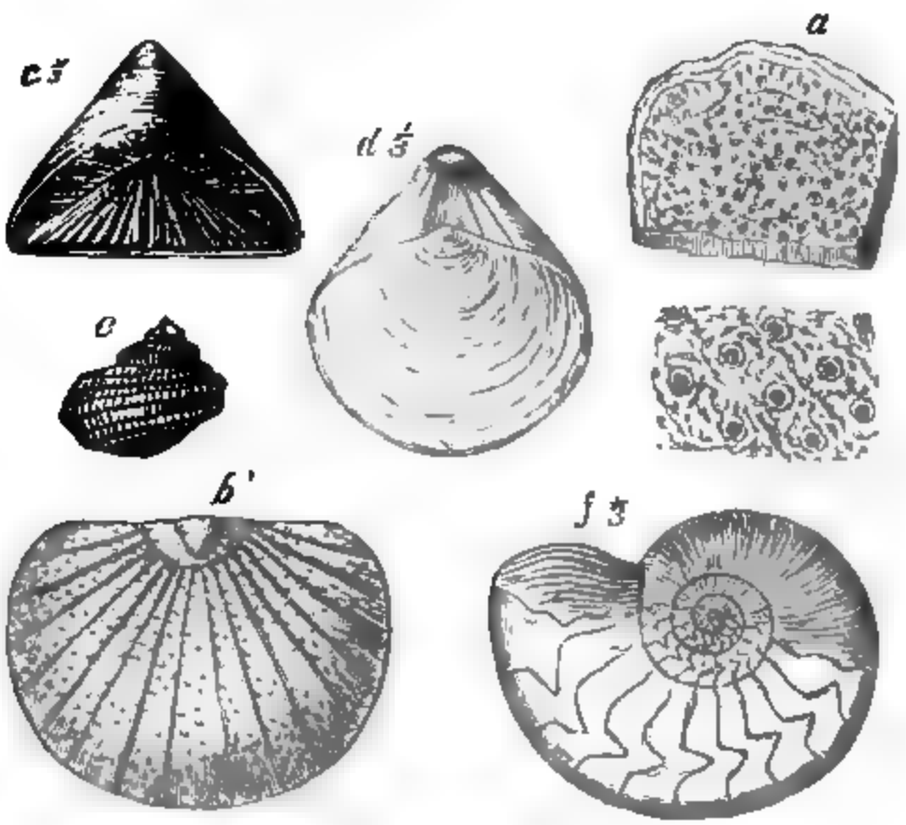

Fig. 52.—GROUP OF DEVONIAN FOSSILS.

a. Stromatopora placenta.
b. Bronteus granulatus (pygidium).
c. Calceola sandalina.
d. Stringocephalus Burtini.
e. Pleurotomaria aspera.
f. Clymenia striata.

Cephalopoda. Mœneceras molarium, M. intermedium, Trochoceras obliquatum, Orthoceras laterale, O. tubicinella, O. Vicaryi

Fossils of the Upper Devonian

Echinoderma. Actinocrinus Porteri.

Crustacea. Phacops granulatus, P. latifrons (also in Mid. Dev.), Cypris (Entomis) serrato-striata.

Brachiopoda. Spirifera Verneuilli, S. Urei, S. distans, Orthis interlineata, Strophalosia productoides, Rhynchonella Partridgue, R. laticosta, R. letiensis.

Lamellibranchia. Avicula damnoniensis, Cucullæa Hardingi, Ctenodonta lirata, Curtonotus elegans (=Myophoria deltoida), Prothyris scalprata, Aviculopecten nexilis, Cardiola retrostriata (Cardium palmatum), Posidonia venusta.

Gastropoda. Loxonema anglicum, Pleurotomaria aspera.

Cephalopoda. Gephyroceras intumescens, Beloceras sagittarium, Clymenia undulata, Clymenia striata, Bactrites gracilis.

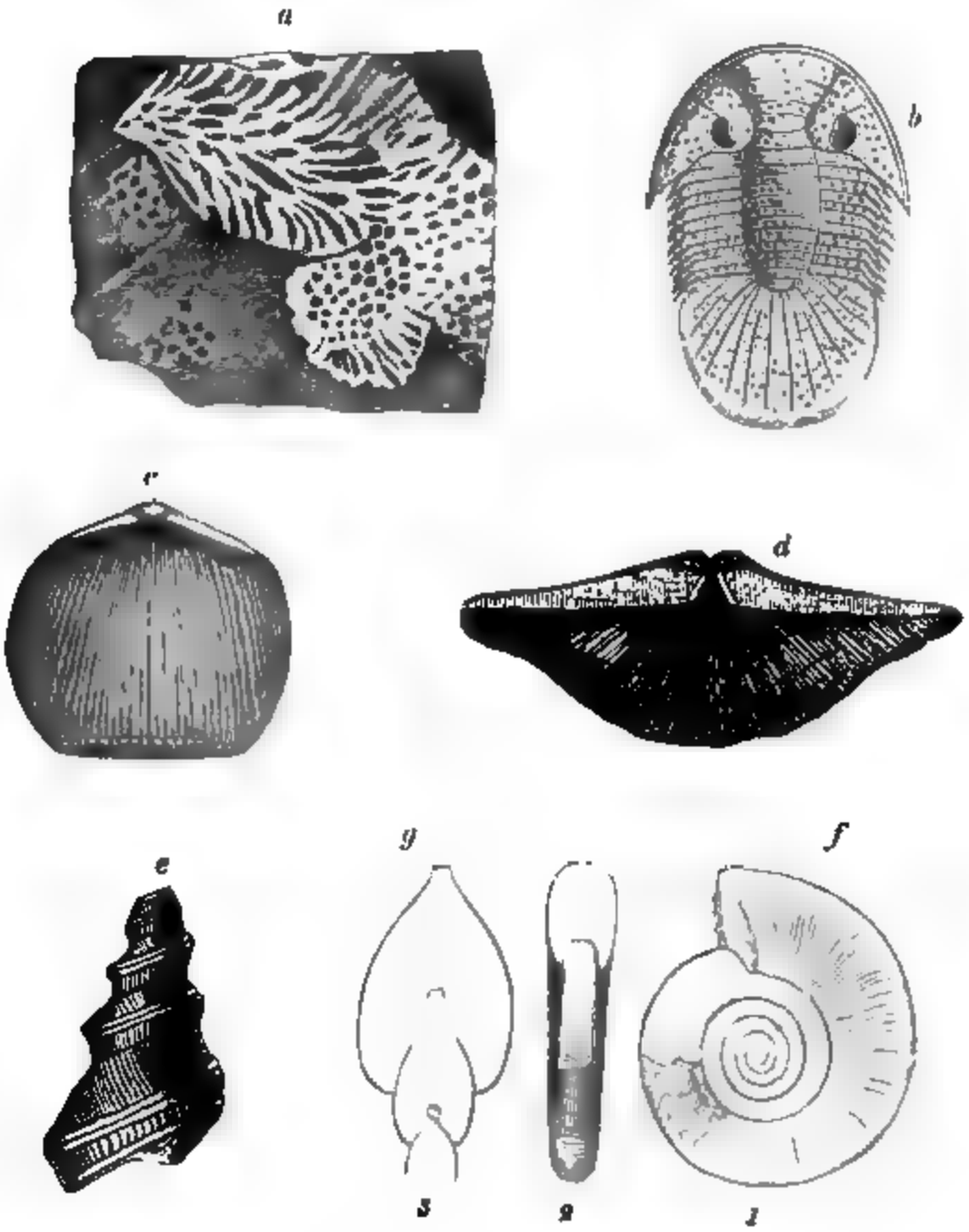

Fig. 53.—GROUP OF DEVONIAN FOSSILS.

a. Favosites polymorpha.
b. Bronteus granulatus.
c. Rhynchonella cuboides.
d. Spirifer disjuncta (=Verneuilli), var extensa.
e. Murchisonia angulata.
f. Clymenia undulata.
g. Section through Clymenia striata to show position of the siphuncle.

Stratigraphy

The Devonian rocks in England have been so crushed, plicated, and faulted that it is no easy matter to make out the original order of succession in either North or South Devon ; moreover, though fossils are abundant and fairly well preserved in the limestones, they are often so crushed and deformed in the shales and sandstones that they are difficult to recognise specifically. On the continent, however, and especially in a large area extending through the south of Belgium and Rhenish Prussia to Siegen and Wiesbaden, the rocks are not so crushed and broken, so that the order of succession has there been satisfactorily determined. Thus, though the Devonian system was first established in England and bears an English name, it seems probable that in respect to its subdivisions the Belgian and German districts must always serve as the standard. In these circumstances it will be convenient to give some account of the continental succession before describing the English rocks, and for this purpose the Belgian facies seems to offer the best basis of comparison.

1. *Belgium*

In the Belgian Ardennes Devonian rocks occupy the greater part of a region which is over 100 miles in length and has a maximum width of about 50 miles, extending from Avèsnes in the French Ardennes to the western part of the Eifel district on the German border. This district may be described as a large basin which includes many smaller troughs and anticlines. Fig. 54 is a section across a portion of it, and will illustrate the general succession of the Devonian series, the total thickness of which is estimated at about 14,000 feet.[1a]

Lower Devonian.—The basement beds of this division rest unconformably on the Cambrian of the Ardennes, and consist of a conglomerate succeeded by a series of green slates and flagstones. These are known as the *Gedinnian*, but have yielded very few fossils. Above them is the *Coblentzian* series, having the white sandstone of Anor at its base, followed by the graywacke of Montigny and the grits and slates of Vireux, Burnot, and Hierges, the whole being from 7000 to 8000 feet thick. The Anor sandstone has a special fauna, including *Spirifer primævus*, *Renssellæria crassicosta*, *R. strigiceps*, *Avicula lamellosa*, and *Kochia capuliformis*, and appears to represent a series of beds which are more fully developed near Coblentz, and are known as the Taunus quartzite and Hundsrück slates. The grits and mudstones above this white sandstone are characterised by *Spirifer paradoxus*, *S. hystericus*, *Rhynchonella*

daleidensis, *Meganteris Archiaci*, *Chonetes sarcinulata*, *C. dilatata* and *Pleurodictyum problematicum*. At the top are beds containing *Spirifer cultrijugatus*.

Middle Devonian.—The Calceola slates consist of calcareous slates and earthy limestone rich in fossils. Stromatoporoids are abundant, as also are corals, such as *Calceola sandalina*, *Heliolites porosa*, *Cyathophyllum helianthoides*, and *Alveolites suborbicularis*. Brachiopoda also abound, especially *Spirifer speciosus*, *S. curvatus*, *Pentamerus galeatus* (*? brevirostris*), and *Athyris concentrica*.

The upper stage of the Middle Devonian is a massive limestone 1300 feet thick, and is well seen at Givet on the Meuse, whence it is known as the Givétien. Fossils are not numerous and are difficult to extract, but include *Stringocephalus Burtini*, *Spirifer mediotextus*, *Uncites gryphus*, *Megalodon cucullatum*, several species of *Murchisonia*, and corals.

Upper Devonian.—This also falls naturally into two stages. The lower (Frasnian) consists in the lower part of shales with lenticular limestones (calcaires de Frasne) rich in fossils, *Spirifer Verneuilli*, *S. orbelianus*, *Rhynchonella cuboides*, *Camarophoria formosa*, etc. Above these are shales with *Gephyroceras intumescens*, *Cardium* (*Cardiola*) *palmatum*, and others with *Bactrites* and *Cypridina*.

The higher stage (Famennian) consists of greenish slates with *Spirifer Verneuilli*, *S. distans*, and many *Rhynchonellæ* (*R. letiensis*, etc.), and at the top a limestone containing a mixture of Devonian and Carboniferous species. In another part of the Ardennes these beds appear to be represented by soft brown micaceous sandstones (Psammites du Condros), which yield some of the same fossils, together with *Cucullæa Hardingi*, *Orthis crenistria*, *Phacops latifrons*, and *Palæopteris hibernica*.

2. *South Devon and North Cornwall*

As stated on p. 175, the rocks in this area are so broken by faults and plicated by pressure that it is very difficult to make out their order of succession, and apparently impossible to estimate their original thickness. It will be noticed that the section, Fig. 55, shows a general inclination of the beds toward the north, newer and newer beds coming on in that direction. This is the rule in South Devon and North Cornwall, and yet the prevalent dips actually observed and recorded on the maps of the Geological Survey are toward the south, which would lead one to infer a complete inversion of the beds. Mr. Ussher informs me, however, that these dips appear to be those of the minor plications, for not only is the whole system flexured into a succession of curves, but each flexure

Fig. 54.—SECTION THROUGH THE SOUTHERN PART OF THE DINANT BASIN, ARDENNE (after Professor Gosselet).
Distance about 12 miles.

9. Limestone of Givet.
8. *Calceola* shales.
7. Graywacke of Hierges.
6. Red shales of Burnot.
5. Sandstone of Vireux.
4. Graywacke of Montigny.
3. Anor sandstone (Grès d'Anor).
2. Schists of Mondrepuits, etc.
1. Arkose and conglomerate.
A. Cambrian slates.

N

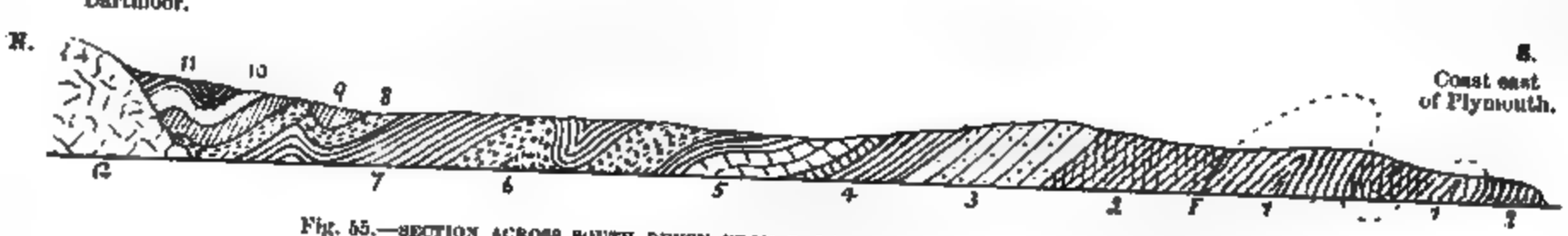

Fig. 55.—SECTION ACROSS SOUTH DEVON FROM DARTMOOR SOUTHWARDS. Distance about 9 miles.
Drawn from a sketch-section by Mr. Usher

11. Culm-measures.
10. Petherwin beds } Upper
9. Entomis slates } Devonian.
8. Goniatite beds }
7. Slates (Upper and Middle Devonian).
6. Ashprington beds.
5. Middle Devonian limestone.
4. Eifelian slates
3. Staddon grits } Lower
2. Meadfoot beds } Devonian.
1. Dartmouth slates }
G. Granite of Dartmoor.

is frilled into smaller plications. The following account is taken chiefly from recent papers by Mr. Ussher, who has been occupied for many years in mapping South Devon.[1]

Lower Devonian.—The actual base of this series has not yet been found, but it is suspected that Silurian rocks occur near Fowey and St. Austell, and consequently the base of the Devonian may eventually be found in that district. Near Looe, on the Cornish coast, there are slates and grits containing badly preserved trilobites and brachiopods which seem comparable to species found in the Gedinnian or lowest Devonian group of the continent. Among these are Phacops (*Dalmanites*) *laciniatus*, *Spirifer primævus*, *S. hysterica*. Owing to faults, however, their relation to the neighbouring purple and green slates of Polperro and Talland cannot be proved, and lithologically the Looe beds resemble the Meadfoot beds to be mentioned below.

The Polperro slates include beds of hard grit or quartzite, and are identical in character with the Dartmouth slates, which form a nearly continuous band across South Devon from the mouth of the Yealm to that of the Dart. In this area these Dartmouth Slates and grits appear to be the lowest and oldest group; they are succeeded by the Meadfoot Beds, gray and purple slates and thin grits often stained red, with thin lenticular calcareous layers, the whole being probably not more than 400 to 500 feet thick. Above these are the Staddon Grits, consisting of hard reddish sandstones or grits which may be 300 feet thick; they are well seen at Staddon near Plymouth and Cockington near Torquay, as well as on the Lincombe and Warberry hills above Torquay (see map, Fig. 56).

The Meadfoot Beds have also been called the *Homalonotus* beds, as they contain *Hom. armatus*, *H. crassicauda*, with *Spirifer hystericus*, *S. paradoxus*, and *Pleurodictyum problematicum*. The Staddon grits have yielded at Lincombe and Cockington *Homalonotus Champernowni*, *H. gigas*, *Spirifer cultrijugatus*, *Leptæna laticosta*, *Chonetes sordida*, *C. sarcinulata*, and *Pleurodictyum*. From the presence of these species it is evident that this series represents the Coblentzian of Belgium and the Rhine.

Middle Devonian.—In its prevalent facies this consists of gray slates with interbedded bands of volcanic tuff and schalstein and lenticular beds of limestone, but in some places, as near Torquay and Brixham, the whole division seems to be represented by thick masses of limestone which are probably from 400 to 500 feet thick, but do not extend for any great distance. The area south of Totnes presents the greatest development of volcanic material, eruptions having taken place in this district from the date of the earliest (Eifelian) slates to Upper Devonian time, so

that the limestones are here entirely represented by volcanic rocks.

The tuffs and slates furnish few fossils, while the limestones have yielded a large number, so that greater interest attaches to the limestone tracts in spite of the fact that they are isolated masses, and are an exceptional rather than a normal facies. At the base of the limestones there are always shales with thin layers of limestone which have yielded *Spirifer speciosus*, *S. curvatus*, *Atrypa reticulata*, *Calceola sandalina*, *Cyathophyllum helianthoides*, and other corals. These beds seem to represent the Calceola shales of Belgium (Eifelian), and may be 200 feet thick.

Higher limestones are found at Plymouth, Brixham, Torquay, Darlington, Ashburton, and around Newton Abbot. They are generally gray, but sometimes mottled with brown or pink, and are often quarried for ornamental marbles. They vary much in character and in degree of alteration or marmorisation. In some places they are full of corals and have the aspect of ancient coral-reefs; in others they are rich in brachiopods and other shells (as at Lummaton and Woolborough); and again in other places they are so highly marmorised that no organisms can be extracted, though they are visible in polished slices. These middle limestones have yielded a large fauna which has been described and illustrated by Mr. G. F. Whidborne;[2] it is comparable to that of the "calcaire de Givet," and includes *Stringocephalus Burtini*, *Pentamerus brevirostris*, *Cyrtina heteroclita*, *Rhynchonella acuminata*, *Conocardium clathratum*, *Bronteus granulatus*, *Murchisonia turbinata*, *Heliolites porosus*, *Cyathophyllum cæspitosum*, *Favosites polymorpha*, and many others.

Upper Devonian.—There appears to be a complete passage from the Middle Devonian into limestones of Upper Devonian (*i.e.* Frasnian) age, but in this part of the series the beds resemble those of the Rhine more than those of the Franco-Belgian area. Limestones containing *Rhynchonella cuboides*, and *Spirifer bifidus* have been found near Ramsleigh, Chudleigh, Kingsteignton, and elsewhere, but they cannot be identified with certainty as equivalents of the "calcaire de Frasne" because *Rhynchonella cuboides* is not confined in England to such a high horizon, but is common in the Middle Devonian.

Near Chudleigh and Kingsteignton the gray massive limestones with *Rhyn. cuboides* and *R. acuminata* are overlain by red nodular limestones which contain *Gephyroceras intumescens*, *G. acutum*, *Tornoceras simplex*, with *Cardiola retrostriata* and *Phacops cryptophthalmus*. Similar limestones associated with red shales occur at Saltern Cove (Torbay) and other places, and they are succeeded by red and green shales which contain the small crustacean *Entomis serratostriata*,

Ilfracombe
Lundy I.
Morte Pt
Hartland Pt
Bude
Barnstaple
EXMOOR
SOMERSET
DEVON
EXETER
Tiverton
Sidmouth
Budleigh
Exe
Teignmouth
DARTMOOR
BODMIN MOOR
CORNWALL
Tavistock
Torquay
Paignton
PLYMOUTH
Dart
Rame Hd
Thurlestone
Start Pt
Bolt Hd
Tertiary
Cretaceous
Trias
Keuper Sandstone
Marls
Permian
Breccias
Upper Culm
Middle Culm
Lower Culm
Upper & Middle Devonian
Lower Devonian
Schistose Rocks
Granite
GEOLOGICAL MAP
OF PARTS OF
SOMERSET, DEVON
& CORNWALL
AFTER W. A. E. Usher
SCALE OF MILES
0 5 10 20 30

Fig. 50.

with *Posidonia venusta.* These are the "Cypridinen-schiefer" of German geologists, and may be regarded as highest Frasnian or as a passage into Famennian.

Here and there in the south-east of Devon still higher beds containing species of *Clymenia* have been found, and near Ashburton are slates containing *Spirifer Verneuilli* and *Rhynchonella letiensis*, which are certainly Famennian. West of Dartmoor these beds have their equivalents in the well-known Petherwin beds, which are gray slates with thin lenticular limestones. These have yielded many fossils, of which the following are some; *Clymenia lævigata*, *C. striata*, *C. undulata*, *Orthoceras striatum*, *Tornoceras lineare*, *Ctenodonta antiqua*, *Sanguinolites elliptica*, *Strophalosia productoides*, *Spirifer Verneuilli*, *S. Urei*, and *Phacops granulatus.*

3. *North Devon and West Somerset*

In this area the rocks appear to form an ascending succession from north to south, and Fig. 57 is a diagrammatic section to show this apparent order with slight indications of the faults and contortions. In reality, however, there are many faults, and all the beds are flexured, plicated, and cleaved. The regularity of the succession has been repeatedly questioned. Jukes was the first to suspect the existence of a great fault along the southern boundary of the Morte Slates,[3] but he imagined that these slates were of Carboniferous age, and that the whole of the North Devon rocks were duplicated by the fault, the Pickwell Down beds being a repetition of the Foreland beds, and the succeeding beds on each side of the fault being comparable with one another. This view was combated by Mr. Etheridge,[4] who found it easy to show that the fossil evidence made it untenable, for the fossils of the Lynton beds are unquestionably Lower Devonian, while all the fossils found in beds south of the Pickwell Down group are with equal certainty of Upper Devonian or Carboniferous age.

When Mr. Etheridge wrote, no fossils had been found in the Morte Slates, but in 1895 and 1897 Messrs. Hicks and Whidborne [5] found fossils at several places along their outcrop, and the assemblage appears to indicate the existence of a Lower Devonian fauna. In the papers referred to Dr. Hicks stated his belief that not only is there a fault along the southern boundary of the Morte slates, but one along their northern border, that these slates are in fact thrust up between the two lines of fault, and that they are the oldest rocks in North Devon.

Again the junction of the Foreland Sandstones with the Lynton beds appears to be everywhere a faulted one, so that there is no proof of the former being older than the latter. It will be seen,

therefore, that our knowledge of the geology of North Devon is not yet very complete; at present it is only possible to give the apparent order of succession and to indicate the points that remain for determination.

Lower Devonian.—The rocks which have hitherto been regarded as the oldest in North Devon are the Foreland Sandstones; they occupy the coast from Minehead to Hurlstone Point and from Porlock to Foreland Point east of Lynmouth, and consist of hard, fine-grained, red, brown, and gray grits or sandstones, with some coarse and pebbly beds. Near Lynmouth they are bent into a bold anticline, and, rolling over to the south, are faulted against the Lynton Slates in the valley of the Lynn brook (see Fig. 57). No fossils except plant remains have yet been found in them, but there is much resemblance between this series of beds and the Hangman grits.

The Lynton Beds consist chiefly of hard slates with some beds of grit and occasional calcareous bands, and are supposed to be from 1200 to 1500 feet thick. Fossils are fairly abundant, but in a bad state of preservation. The following have been recorded: *Spirifer hystericus*, *S. lævicosta*, *Orthis arcuata*, *Chonetes sordida*, and *Favosites polymorpha*. These beds are succeeded by the Hangman Grits, which consist of brown, green, yellow, and red sandstones with some coarse red and speckled grits in the upper part. They form the cliffs between Woodabay and Combe Martin Bay, and are probably more than 1500 feet thick. No fossils except a few casts in the highest beds have been found.

As compared with South Devon the Lynton Beds appear to correspond with the Meadfoot Beds, and the Hangman Grits with the Staddon Grits, but unless the Foreland beds are a repetition of the Hangman Grits there is no parallel to them in South Devon.

Middle Devonian.—At Combe Martin Bay a series of slates and gritty flags with layers of impure limestone comes in, and these are sometimes called the Combe Martin Beds, but are only the lower part of the Ilfracombe series, which occupies the coast for a long distance and forms a continuous band through North Devon and West Somerset. The higher beds of this series are silvery gray slates with lenticular bands of limestone, and have yielded many species of characteristic Middle Devonian fossils. The beds are intensely plicated, compressed, and cleaved, the observed dips being generally those of isoclinal folds, with both limbs of the flexure dipping in the same direction. Consequently until the country has been more minutely examined no reliable estimate of thickness can be formed.

The Morte Slates form a continuous band to the south of

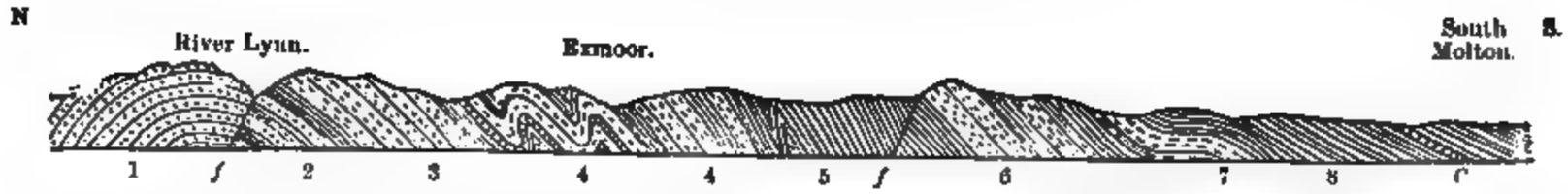

Fig. 57.—DIAGRAMMATIC SECTION ACROSS NORTH DEVON SHOWING THE APPARENT ORDER, BUT NOT THE TRUE POSITION OF THE MORTE SLATES. Distance about 15 miles.

8. Pilton beds.
7. Baggy beds.
6. Pickwell Down beds.
5. Morte slates.
4. Ilfracombe beds.
3. Hangman grits.
2. Lynton beds.
1. Foreland sandstones.
C. Lower Carboniferous.
ff. Faults.

Fig 58.—SECTION ACROSS BRECKNOCKSHIRE FROM THE TREWERNE HILLS TO NEAR CRICKHOWEL (after Murchison). Distance about 18 miles.

8. Carboniferous rocks.
7. Upper Old Red Sandstone.
6. Brownstone series.
5. Red marls and sandstones.
4. Red marls and cornstones.
3. White sandstones.
2. Red marls and flagstones.
1. Ludlow beds.

the Ilfracombe beds, and consist of glossy green and gray slates with numerous quartz veins. As already stated the fossils which have been found in them point to their being of Lower Devonian age and not Middle Devonian, as usually supposed. These fossils were obtained from Morte Bay and Mullacott on the coast, and from Treborough in Somerset. Some of the species are described as new (such as *Lingula mortensis*), some resemble Silurian forms, such as *Orthis rustica*, and others are Lower Devonian, *e.g. Phacops (Dalmanites) laciniatus*, *Strophomena tæniolata*, *S. explanata*, *Chonetes plebeia*, and *C. sarcinulata*.

Upper Devonian.—This series has been divided into three stages, the lowest being the Pickwell Down Beds, a set of red, purple, brown, and green sandstones with intercalated bands of shale. They are traceable from Pickwell Down near Morte Bay to Wiveliscombe in Somerset, but the only fossils yet found are fish remains and fossil wood.

The Baggy Beds consist of green shales and yellowish sandstones and flags, and extend inland from Baggy Point, north of Croyde Bay, by Marwood and Sloly, where are quarries from which many fossils have been obtained, including *Avicula damnoniensis*, *Cucullæa*, *Hardingi*, *Rhynchonella laticosta*, *Spirifer Verneuilli*, *Strophalosia productoides*, *Chonetes hardrensis*, and plant remains (*Stigmaria* and *Knorria*). Some of these species range into the Carboniferous series and are figured on p. 206.

The Pilton Beds consist of bluish gray slates with thin bands of limestone and of sandstone. They stretch from Croyde Bay inland by Braunton and Pilton and are highly fossiliferous, containing among others *Phacops latifrons*, *Productus prælongus*, *Spirifer Verneuilli*, *S. Urei*, *Orthis interlineata*, *Aviculopecten nexilis*, *A. transversus*, *Loxonema anglicum*, and other gastropoda. They appear to pass upward into the Lower Carboniferous shales (see p. 216), and the divisional line has not yet been fixed, but Mr. Salter believed that the soft slates which are troughed into the flexures of the Pilton beds near Barnstaple should be classed as Carboniferous.

The Upper Devonian series of North Devon differs greatly from that of South Devon, and none of the characteristic Upper Devonian *Goniatites* and *Clymeniæ* have yet been found in it.

B. The Old Red Sandstone Type

When we cross the Bristol Channel from North Devon to South Wales we reach an entirely different lithological type, for in Wales the beds between the Silurian and Carboniferous are all of the Old Red Sandstone facies. These rocks occupy a large

area between the Silurian tract and the valley of the Severn, and in the south of Brecknock they form a range of lofty hills

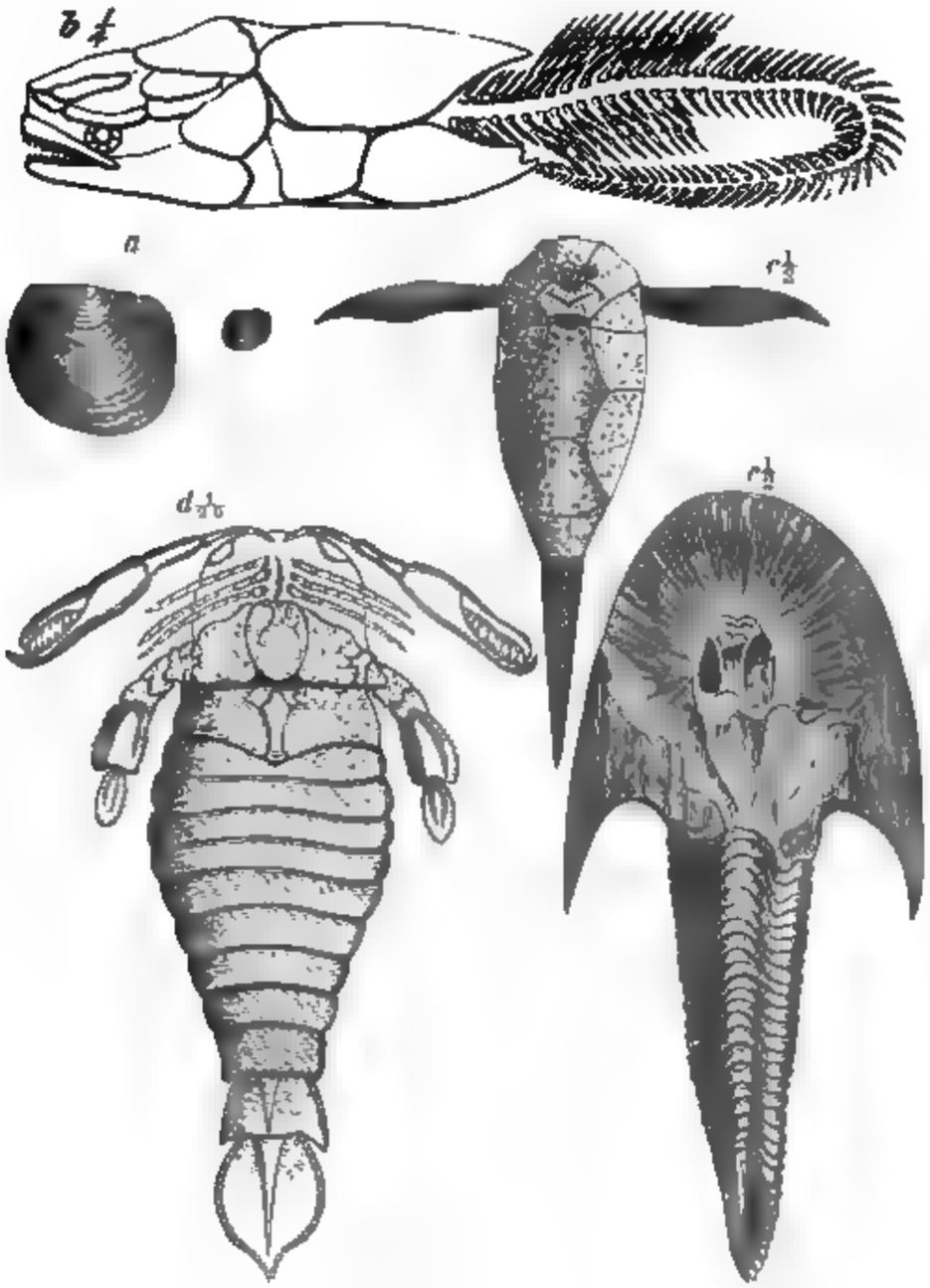

Fig 59.—FOSSILS FROM THE OLD RED SANDSTONE.

a. Estheria membranacea. *c*. Pterichthys Milleri
b. Coccosteus decipiens. *d* Pterygotus anglicus.
e. Cephalaspis Lyellii.

overlooking the great coal-field of South Wales; they surround the Silurian inliers of Usk and Woolhope, and extend northwards to the neighbourhood of Wenlock in Shropshire.

No more of this Old Red Sandstone is seen till we reach the borders of Scotland, where it is found in the Cheviot Hills. It attains an enormous thickness in the central parts of Scotland, where it includes massive sheets of interbedded volcanic rocks, and it occurs again in the north-east of the country, in Moray, Caithness, and the Orkneys. The large tracts which this formation

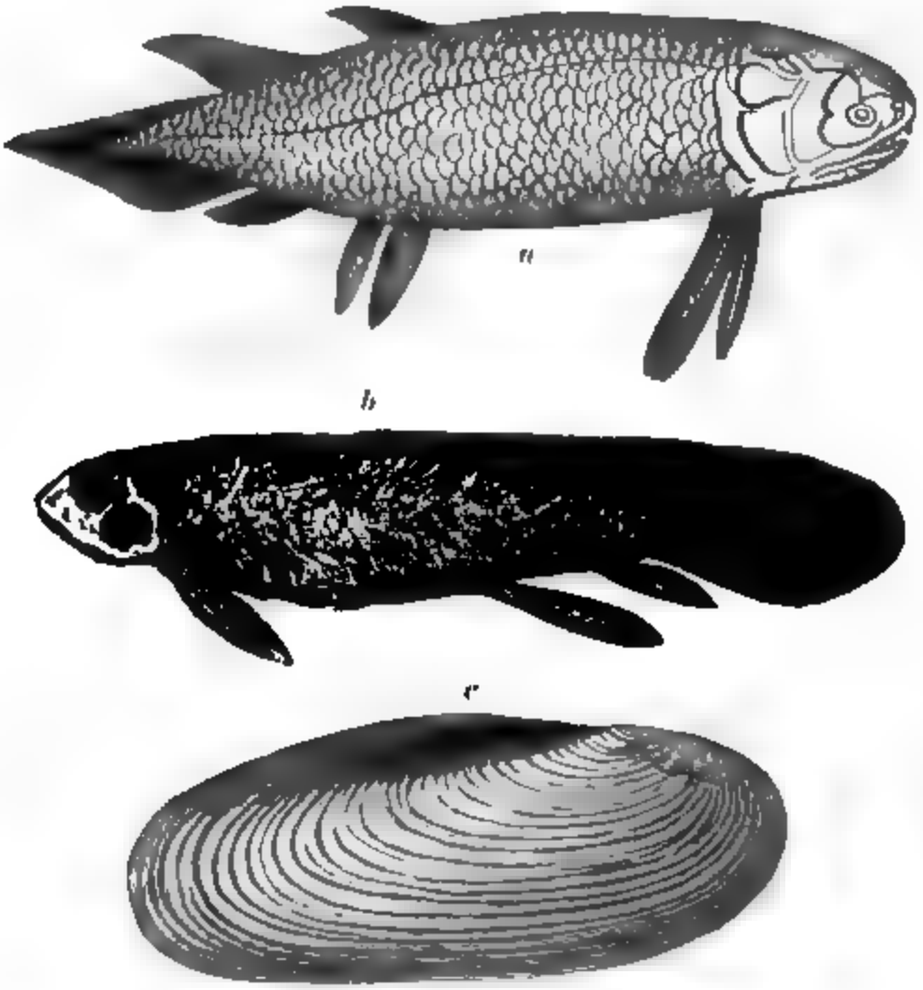

Fig. 60. GROUP OF UPPER OLD RED SANDSTONE FOSSILS.
a. Holyptychius nobilissimus. b. Phaneropleuron Andersoni.
c. Archanodon Jukesi.

still occupies in Scotland, and the manner in which certain outlying patches of it rest on the older Palæozoic rocks, make it probable that it must originally have had a wide extension in that country, and must have entered deeply into the hollows and valleys of the Central Highlands.

In Ireland the lower part of the series (Glengariff beds) is again somewhat different, but the upper part is of the Old Red Sandstone type. The Glengariff grits occupy a large area in

Kerry and West Cork, forming the greater part of the promontories which separate Dingle, Kenmare, and Bantry Bays. The Fintona beds, supposed to be of same age, form a tract about thirty-five miles long by ten in breadth between Lough Erne and Pomeroy in Tyrone. These groups are believed to represent the Lower Old Red Sandstone of Scotland, but the rocks usually called Old Red Sandstone in Ireland form an upper series and attain their maximum development in Kilkenny, Waterford, and Tipperary.

Fossils of the Old Red Sandstone

Fossils are not abundant in the Old Red Sandstones, and such as have been found are principally plants, Eurypterida, and fish. The plants are the ancestors of the Carboniferous flora, and are chiefly lycopods and ferns. The former include *Lepidodendron*, *Sagenaria*, *Knorria*, *Stigmaria*, and *Psilophyton*; ferns are represented by *Palæopteris*, *Neuropteris*, and *Sphenopteris*; Calamites occur, and coniferous wood is also not uncommon.

Fish are the most conspicuous and abundant members of the fauna, and several orders are represented. The Ostracoderms by *Cephalaspis*, *Pteraspis*, *Scaphaspis*, and *Holaspis*; the Dipnoids by *Coccosteus*, *Phaneropleuron*, *Dipterus*, and *Homosteus*; the Elasmobranchs by *Acanthodes*, *Cheiracanthus*, *Diplacanthus*; the Crossopterygians by many genera, such as *Osteolepis*, *Glyptolepis*, *Gyroptychius*, *Diplopterus*, and (in the upper division) *Holoptychius*. The remains of fish are very abundant at certain horizons in Scotland, but they are not generally distributed through the mass of the formation.

The only other organic remains found in British strata are Isopod crustacea, myriapods, and a freshwater mollusc (*Archanodon*), closely allied to the existing *Anodonta*. In Canada, however, insects of several kinds have been found in rocks of corresponding age and character. The following are some of the more characteristic Old Red Sandstone fossils :—

Fossils of the Lower Division

Plants.	Psilophyton robustum, Lepidodendron nothum, L. gaspeanum.
Myriapoda.	Kampecaris, Archidesmus Macnicoli.
Arthropoda.	Pterygotus anglicus, Eurypterus pygmæus, Stylonurus Symondi; Præarcturus gigas.
Pisces.	Cephalaspis Lyelli, Pteraspis rostrata, Scaphaspis Lloydi, Pterichthys cornutus, Pt. Milleri, Coccosteus decipiens, Osteolepis microlepidotus, Acanthodes Peachi, A. Mitchelli, Dipterus Valenciennesi, Diplacanthus gracilis, Glyptolepis elegans, Parexus incurvus.

Fossils of the Upper Division

Plants.	Palæopteris hibernica, Cyclostigma kiltorkense, Knorria bailyana.
Mollusca.	Archanodon Jukesi.
Pisces.	Holoptychius nobilissimus, Pterichthys major, Glyptolemus Kinnairdi, Phaneropleuron Andersoni, Glyptopomus minor.

Stratigraphical Details

1. *The Welsh Borders*

In Monmouth, Hereford, and Brecknock a great thickness of red sandstones and marls intervenes between the Silurian and the Carboniferous, and from these counties extensions of Old Red Sandstone stretch westward through Caermarthen and South Pembroke, northward into Radnor and Shropshire, and eastward into Worcester and Gloucester. It is evident, therefore, that in all these directions the formation originally extended considerably beyond its present limits. Its maximum thickness has been estimated at 10,000 feet, but it is doubtful whether it is anywhere so thick. In the central parts of Hereford and Brecknock it may reach 6000 feet, but a recent measurement at Abergavenny in Monmouth gives only 4200 feet, and farther south, at Newport, only 3500 feet, while to the north, in Shropshire, its thickness is only 3700 feet.

The Old Red Sandstone of this region has been divided[6] into three portions, and though these are of very unequal thickness it seems convenient to retain them until their palæontological relations are better known. It has been thought that a break and unconformity might exist somewhere in the series, but the recent work of the Geological Survey in Monmouth seems to show that the succession is regular and conformable throughout.[7] Thus, until the middle beds are shown to be more closely connected with the upper than with the lower, their retention as a separate group emphasises the completeness of the sequence. These divisions are as follow :—

	Feet.
Upper Series.—Red and yellow sandstones and conglomerates	200-500
Middle or Brownstone Series.—Brown and gray sandstones .	500-1500
Lower or Cornstone Series.—Red and mottled marls with cornstones and bands of micaceous sandstone. . . .	2500-4000

The **Cornstone Series** is so named from the frequent occurrence of lenticular layers of compact limestone, generally red or gray, which are locally called "cornstones." In Monmouth the base of

CORRELATION TABLE OF THE OLD RED SANDSTONE

	Welsh Borders.	Lanark and Pentland.	Perth, Forfar, and Fife.	Caithness and Moray.	Ireland.
Upper.	Yellow sandstones, red sandstones, and conglomerates, 500 feet.	Red sandstones and conglomerates, 500 to 2000 feet.	Dura Den beds, yellow sandstones, Red sandstones, and conglomerates.	Red and yellow sandstones, 800 feet.	Kiltorkan beds, Red sandstones and conglomerates, 500 to 3500 feet.
Middle.	Brownstone series, 500 to 1500 feet.	Absent.	Absent.	Absent.	Absent.
Lower.	Coraistone series, 3000 to 4000 feet.	Caledonian O.R.S., Red sandstones, shales, and conglomerates, 8000 feet.	Caledonian O.R.S., Sandstones, flagstones, and conglomerates, 18,000 feet.	Caithness flags with sandstones and conglomerates, 16,000 feet.	Glengariff and Fintona beds, ? 8000 feet.

N.B.—In spite of the break which actually exists between the Lower and Upper Old Red of Scotland, it is possible that part of the Caledonian Old Red may represent the Brownstone series of Herefordshire.

the series is taken at a layer of coarse red grit, above which are red marls and micaceous flagstones. About 2000 feet from the base is a band of gravelly conglomerate, above which marls and cornstones occur again for 800 feet. This series has yielded fish remains at several places, notably at Leominster and near Abergavenny, including *Cephalaspis Lyelli*, *C. Salweyi*, *Pteraspis rostrata*, *Scaphaspis Lloydi*, and *S. Lewisi*. A *Pterygotus* and *Stylonurus Symondsi* have been found at Rowlestone together with a large Isopod Crustacean, *Prœarcturus gigas*.

Brownstone Series.—This is a monotonous series of brown and chocolate-coloured sandstones with some red shales. They form the lower slopes of the Brecon Vans and the Black Mountains, where they are of considerable thickness, from 1200 to 1500 feet, but become much thinner to the southward, and are not more than 500 feet thick near Newport. No fossils except fragments of *Pteraspis* and *Cephalaspis* have yet been found in this series.

Upper Series.—This is a more varied group, consisting of quartz-grits and conglomerates in the lower part, and of yellow, gray, and red sandstones in the upper part, with occasional bands of red shales; the highest beds pass up into the Carboniferous shale. Mr. Jukes believed that in spite of the apparent conformity there might be a break at the base of this division, and that it should be regarded as belonging rather to the Carboniferous than to the Old Red Sandstone proper. There can be no doubt that at the time of its formation the physical conditions were rapidly approaching those of the Carboniferous period, and also that some of the beds are either of marine or estuarine origin, for a *Conularia* has been found in them at Farlow in Shropshire, and *Serpulæ* near Tenby. Good sections of these red and yellow sandstones are exposed on the coast of Pembrokeshire, near Tenby, and at the mouth of Milford Haven. A specimen of the freshwater mussel, *Archanondon Jukesi*, has been found near Talcarth in Monmouth; *Pterichthys* and *Holoptychius* occur at Farlow.

2. *Scotland*

In Scotland there are three principal areas where the Old Red Sandstones are found, and where they attain a much greater thickness than in England. These areas are: (1) parts of Berwick and of Northumberland, including the Cheviot Hills; (2) the area of the central lowlands, underlying the Carboniferous rocks and coming to the surface both on the southern and the northern side of the great basin; (3) a large irregular tract in the north-east, from Moray and

Inverness to Caithness and the Orkneys. There is also a small tract in the west (Argyleshire).

Sir Archibald Geikie considers that these four areas were distinct and separate basins of deposit, at any rate during the earlier part of the period; that they were also disconnected from the sea and formed large inland lakes. He has therefore proposed separate names for these basins, calling the south-eastern area Lake Cheviot, the central one Lake Caledonia, the northern basin Lake Orcadie, and the small western basin Lake of Lorne. In all there is the same general succession, viz. a great series of red conglomerates, sandstones, and flagstones, which in most places rests unconformably on all the older rocks, including the Silurian. This series is covered by another set of red sandstones, some of which may represent the Upper Old Red group, but they pass up into Carboniferous rocks, and rest with a marked unconformity upon everything below, including the Lower Old Red.

The following is a brief description of the rocks found in each of the three principal basins.

1. **Cheviot Area.**—In Berwickshire the Lower Old Red forms a band of no great width running from the coast at Eyemouth and Coldingham, along the foot of the Lamberton Hills, till at Auchencraw it is abruptly overlain by the Upper Red Sandstones mentioned below. The older series rests on the upturned edges of the Silurian rocks, and consists of red felspathic sandstones and marls, with beds of volcanic conglomerates and ash. Fragments of *Pterygotus* and obscure plants are the only fossils yet obtained. The Cheviot Hills consist mainly of thick sheets of andesitic lava and tuff, but another tract of Old Red sediments occurs to the south-west of these hills. The volcanic rocks are 2000 feet thick, and the whole may be 3500 feet, but this is only a portion of the original series.

It is doubtful whether any of the Upper Red series is really of Devonian age; the lowermost red beds, containing *Palæopteris hibernica* and fish scales, were formerly classed by the Geological Survey as Upper Old Red, but are now grouped with the Carboniferous. These form a broad band extending, with some interruptions, from Berwick, by Chirnside and Greenlaw, to Jedburgh and Teviotdale. They rest partly on the Lower Old Red and partly on Silurian; their basement beds are breccia and conglomerate, and the higher are red sandstones and marls.

Caledonian Area.—In this area there is an immense thickness of Old Red Sandstone, a lower series, consisting partly of sedimentary and partly of volcanic rocks, and an upper series entirely sedimentary, but of less thickness. On the southern side of the great

Lowland trough these beds crop out in an irregular manner, owing to numerous faults and to the overlap of the Carboniferous rocks; but on the northern side they form a broad tract extending from the Isle of Arran and the Firth of Clyde, through Perth and Stirling, to the coast of Fife and Forfar, a distance of about 170 miles. This broad band of Old Red Sandstone is faulted against the older Palæozoic rocks on its north-west border, but small patches of red sandstone and conglomerate occur beyond the fault, and show that in some places at any rate it extended into the Highland area; it is believed, however, that such extensions are those of beds which are considerably above the real base of the series.

Along the southern tract, in Ayrshire, Lanark, and the Pentland Hills, the sections are incomplete, only a portion of the lower series being visible, and this is overlain unconformably by the upper group, which forms the base of the Carboniferous succession. The beds described on p. 161 as forming the highest member of the Silurian system were formerly classed with the Old Red Sandstone, but the base of the latter is now taken at a band of conglomerate containing greywacke pebbles, which is recognisable in all three districts. Near Lesmahagow (Lanark) this conglomerate rests with apparent conformity on the red Silurians, and is succeeded by chocolate-coloured sandstone containing *Cephalaspis Lyelli;* but in Ayrshire and in the Pentlands the basal conglomerate is markedly unconformable to this Silurian series.[8]

In the Pentland Hills the Lower Old Red comprises a great thickness of variously coloured sandstones and conglomerates, with interstratified sheets of andesitic lava and tuff, the whole being estimated at about 8000 feet (see Fig. 61).

On the northern side of the great basin, and especially in Perth, Forfar, and Kincardine, much more complete sections of the Old Red Sandstone are exposed. The lower series comprises an enormous thickness of sedimentary and volcanic rocks, estimated by Sir A. Geikie to be from 18,000 to 20,000 feet thick, and this is succeeded by the Upper Old Red, which adds another 2000 feet. Mr. Goodchild informs me that the general succession of the lower series in Forfar may be stated as follows in descending order, but the thicknesses given are doubtful:—

	Feet.
4. Red flags and sandstones of Strathmore	2000
3. Thick conglomerates, sandstones, and lavas	8000
2. Red and gray flagstones and shales (Arbroath flags) . .	3000
1. Red shaly sandstones with basal conglomerate. . . .	5000

The Arbroath flags have yielded many remains of plants, fishes, and crustacea, the characteristic fish being *Acanthodes Mitchelli*,

Fig. 61.—DIAGRAMMATIC SECTION ACROSS THE PENTLAND HILLS. Distance about 6 miles.

e. Edge-coal series.
c. Upper Old Red.
c, *b*. Divisions of the Lower Old Red Sandstone.
a. Downton and Ludlow series.
DD. Flows of diabase and andesite.

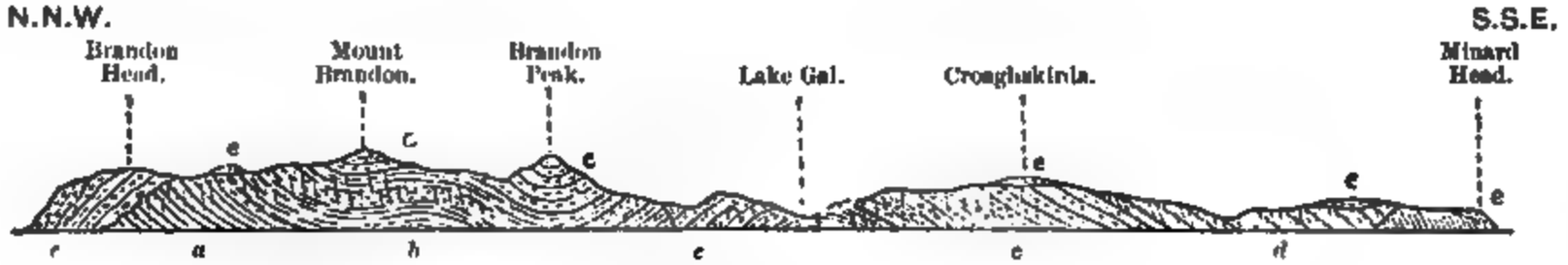

Fig. 62.—SECTION ACROSS THE DINGLE PROMONTORY (after Professor Hull). Distance 6½ miles.

e. Upper Old Red Sandstone.
d. Purple slates } Glengariff beds.
c. Gray grits }
b. Croaghmarhin beds (Ludlow).
a. Ferriter's Cove beds (Wenlock).
f, *f*. Faults.

Diplacanthus gracilis, *Climatius scutiger*, *C. reticulatus*, *Parexus incurvus*, *Cephalaspis Lyelli*, and *Pteraspis Mitchelli*. Of Merostomata there are *Pterygotus anglicus*, *P. minor*, *Eurypterus* (two species), and *Stylonurus* (three species). The plant-remains are chiefly linear, sedge-like leaves, with species of *Psilophyton* and *Lepidodendron*.

The conglomerates are very coarse, consisting of water-worn pebbles and rounded blocks of quartzite, quartz-porphyry, granite, and various schists, all derived from the Central Highlands, with some fragments of andesite derived from contemporaneous lavas (see p. 198).

In the Ochil Hills there are also coarse breccias, consisting largely of volcanic blocks, with which many rounded pebbles are mingled, this mixture of water-worn detritus and angular blocks probably indicating the proximity of a volcanic vent.

The Upper Old Red of this district consists in the lower part of red conglomerates and sandstones with several beds of cornstone and siliceous limestone, and the higher beds are yellow sandstones and shales. These beds form a continuous tract between the lower series and the Carboniferous sandstones from Kinross and Loch Leven to Cupar and the mouth of the river Eden. The yellow beds are well exposed at Dura Den near Cupar, and some of them are crowded with the remains of certain fish, such as *Pterichthys major*, *Holyptychius nobilissimus*, and species of *Glyptopomus*, *Glyptolæmus*, and *Phaneropleuron* (see p. 176).

Orcadian Area.—In this northern basin the Old Red Sandstone rests upon the metamorphic rocks of the Highlands; its border skirts the hills along the south side of the Moray Firth, and then bends northward through the east of Ross and Sutherland. It occupies the whole of Caithness, most of the Orkney Islands, and parts of the Shetlands, and must have once stretched far into the North Sea. The most complete sections are found in Caithness, where the lower series is divisible into the following groups :—

	Feet.
5. Red sandstones of John o' Groats	2000
4. Flagstones of Huna, etc.	1400
3. Flagstones of Thurso	5000
2. Flagstones of Wick and Lybster	5000
1. Dark red sandstones and conglomerates	2800
	16,200

The lowest beds are coarse and unfossiliferous. The Wick and Lybster beds consist of finer red sandstones, gray flags, and shales; they have yielded a few fish and some plant remains (*Psilophyton*, *Caulopteris*, and coniferous wood). The Thurso group consists of gray flags and shales with some thin limestones, and many of the

beds are bituminous. These flagstones are known as the Caithness flags, and seem to occupy the place of the Arbroath or Forfarshire flags, but it is a curious fact that few of the fish occur both in Caithness and Forfar, though more than sixty species have been described from the Caithness flags. They are characterised by species of *Acanthodes*, *Diplacanthus*, and *Cheiracanthus*, with *Osteolepis microlepidotus* and *Glyptolepis eleyans;* the small crustacean *Estheria membranacea* also abounds.

The highest beds at John o' Groats have yielded a few other fish, including *Acanthodes Peachi* and *Pterichthys Dicki*, and some interesting plants which resemble species found in the Devonian of Canada, such as *Lepidodendron gaspeanum*, *Cyclostigma sp.*, *Palæopteris Browni*, and *Calamites transitionis*, which are evidently forerunners of the Carboniferous flora.

This northern basin includes also some tracts of Upper Old Red, which, as usual, rests with a marked unconformity on the lower series. From 600 to 800 feet of red and yellow sandstones can be seen. They occupy a tract of some length in Moray and Nairn, and outlying patches occur at Tarbat Ness, round Dornoch, at John o' Groats and Dunnet Head, and again in the Island of Hoy.

3. *Ireland*

In Ireland, as in Scotland, the equivalents of the Old Red Sandstone are divided into two series with a great gap between them, so that the lower series seems linked to the Silurian, and the upper series to the Carboniferous rocks, and where both occur the one rests unconformably upon the other.

The lower series has been found in four separate districts: one in Cork and Kerry, where they are called the Glengariff beds; another to the north, in Tyrone, where they have been called the Fintona series; a third small tract in Antrim, and a fourth in the north of Donegal.

Glengariff and Dingle Series.—In the coast section of the Dingle promontory the beds with Ludlow fossils are conformably overlain by gray, brown, and purple slates without fossils, followed by alternations of gray grits and slates, the grits at length predominating and forming a thick series of hard, massive green and purple grits. The whole of this gritstone series is perhaps 8000 feet thick, and is succeeded by slates of red and purple tints, with beds of conglomerate at Parkmore, which, curiously enough, enclose pebbles containing Silurian fossils. No other fossils have yet been found, and except for the occurrence of these derived pebbles, the whole of these slates and grits might be taken for a

continuation of the Silurian rocks, so similar are they to the underlying fossiliferous series.[9]

A similar set of green grits, surmounted by purple slates with bands of grit, occupies large areas to the south and south-west of Dingle Bay, in the Iveragh and Dunkerron promontories, and in the districts of Killarney, Kenmare, and Glengariff.

Fintona Beds.—In the north of Ireland the lower group occupies an area about 30 miles long by 10 wide, between Lough Erne and Pomeroy, in Tyrone. "It consists for the most part of dark red and purple conglomerates, often coarse and massive, and of purple pebbly and fine-grained sandstones, . . . with sandy shales. The pebbles in the conglomerate, which vary from the smallest size up to blocks over a foot in diameter, consist of purple felstone, grits, schists, and quartzite. Of all these the felstone pebbles are by far in greatest proportion," and have been derived from the breaking up of contemporaneous lava streams, some sheets of which still remain interbedded with the conglomerates.

The third area is on the east coast of Antrim between Cushendall and Cushendun. Here again are conglomerates, consisting partly of quartz pebbles and partly of large blocks of quartz-porphyry, and the patch forms a link between the Fintona beds and the Lower Old Red of the Caledonian area.

Another tract of similar material has been found in Donegal between Lough Swilly and Mulroy Bay. This consists of a basal conglomerate succeeded by chocolate-coloured sandstones and shales with some pebbly beds, and the materials are all derived from the surrounding quartzites and schists. The thickness seen is about 800 feet.

Upper Old Red Sandstone.—In the Dingle district the slates above mentioned are abruptly cut off and covered by coarse red conglomerates, which are estimated to have a thickness of 4000 feet; they overstep the whole of the Glengariff and Ludlow series, and are found again on the northern side of the promontory, resting against the truncated edges of the Wenlock beds (see Fig. 62). There is here, therefore, a great gap and unconformity.

About Tralee and Killarney, however, no such conglomerates are found, but beds of brown and yellow sandstone with red and olive-green shales come in between the Glengariff slates and the Carboniferous shale. Near Tralee these are 600 feet thick, but near Killarney they are only 150 feet, and when the Carboniferous beds are brought in again along the Sneem and Kenmare trough, neither the conglomerate nor the yellow standstone group is to be found. At these places the Carboniferous shale or slate is in contact with the Glengariff grits, and though there is no clear

proof of any unconformity, yet the beds are thrown into such sharp folds, that it would be difficult to detect any slight discordance, and in view of the clear relations of the two series in the Dingle section, Professor Hull's explanation appears a probable solution of the difficulty. He supposes that the Carboniferous beds gradually overlap the Upper Old Red along a shelving bottom, so that they eventually come to rest on the Glengariff series without the intervention of any red conglomerates or sandstones. On the south coast of Cork the yellow sandstones are again found, and *Palæopteris hibernica*, *Sagenaria sp.*, and *Archanodon Jukesi* have been found in them.

As the beds thicken eastwards conglomerates again come in below them, and the unconformity at their base is once more a marked feature. Near Waterford, for instance, they are conspicuous in the cliffs above the railway station, and lie nearly horizontally on vertical Ordovician slates. Above these conglomerates in Waterford and Kilkenny are dark red-brown sandstones, succeeded by gray and purple sandstones with red shales, and finally yellow and greenish sandstones with olive-green shales. These last are known as the Kiltorcan beds, and contain a remarkable assemblage of fossils, including *Archanodon Jukesi*, scales of *Coccosteus* and *Glyptolepis*, *Palæopteris hibernica*, *Sphenopteris Hookeri*, and other plants, and fragments of *Eurypterus*, *Pterygotus*, and *Proricaris*.

This assemblage of fossils marks the Kiltorcan beds as the equivalents of the Upper Old Red Sandstone of Wales and of Scotland, but there is a complete passage from it into the overlying Carboniferous shales. Throughout the rest of Ireland the Carboniferous rocks have at their base a greater or less thickness of red sandstone and conglomerate, which is always unconformable to the older rocks, and it is consequently more convenient to mention these basement beds in dealing with the Carboniferous series.

Contemporaneous Volcanic Rocks

Devon and Cornwall.—No contemporaneous lavas occur either in Wales or in North Devon, but South Devon and Cornwall were sites of some volcanic activity, especially during the middle of the period. Thick beds of *schalstein*, a German term for schistose diabase tuffs, occur in the middle Devonian and form a continuous band from Torbay to Plymouth. They were described by the late Mr. Champernowne,[10] and are known as the Asprington volcanic group from their broad development around that place. Dr. Hatch speaks of the rocks which he examined as tuffs and diabases, mostly aphanitic, but sometimes porphyritic, and as closely

resembling the schalsteins of Nassau and the Hartz. Some of the beds are probably altered diabase flows, and there are also many intrusive bosses of less altered diabase, some of which may be the sites of eruptive vents.

In Cornwall, Mr. J. A. Phillips[11] has described several tracts of volcanic rocks, those between Camelford and Trevose Head being clearly contemporaneous, and consisting of sheets of compact dolerites, vesicular lavas, and beds of ash, but in many of the dolerites the augite has been partially or wholly converted into hornblende. There are also intrusive dolerites, which are probably of Devonian age, because they are displaced by the post-Carboniferous granite bosses.

The Cheviots.—In this district thick sheets of andesitic lava and tuff are interstratified with the Lower Old Red Sandstone. Mr. Teall states[12] that these andesites fall into three groups, characterised respectively by the minerals hypersthene, augite, and mica. "The presence of tuffs, vesicular lavas, and amygdaloidal varieties of lava and actual evidences of flow, proves that the conditions of eruption were substantially identical with those of modern times." He also describes some bosses of augite-granite which may possibly be the cores of the volcanoes whence the andesitic lavas were ejected. These eruptions were followed at a later period by the intrusion of quartz-felsite dykes. Similar rocks are found in the Lower Old Red Sandstone of Roxburgh and Berwick. Near Eyemouth, on the coast, there is a mass of very coarse agglomerate, which suggests the immediate neighbourhood of a volcanic orifice, especially as the stratified ash beds become finer in texture both northward and south-westward and as the interbedded felstones likewise thin out in the same directions.

The Scottish Midlands.—In the area called by Sir Archibald Geikie "Lake Caledonia" there was an enormous outpouring of andesitic lavas. The disposition of these lavas and the existence of some actual volcanic vents have led to the inference that the volcanoes were arranged in two parallel lines running along the whole length of the lake at a distance of about twenty miles from each other. If the Irish centre is included, the sites of volcanic activity may be indicated as below :—

Northern Chain.	Southern Chain.
1. The Ulster centre.	5. The Ayrshire group.
2. The Arran and Cantyre centre.	6. The Duneaton centre.
3. The Sidlaw and Ochil Hills.	7. The Biggar centre.
4. The Montrose centre.	8. The Pentland volcano.

Descriptions of all these areas will be found in Sir Archibald Geikie's work on *British Volcanoes*, and it must suffice if a few

particulars are here given respecting the third and eighth of these centres.

The Sidlaw and Ochil Hills form a chain of about sixty miles in length, and their features are wholly due to the immense masses of volcanic rock of which they consist, most of the ridges being the scarped outcrops of inclined lava-flows, though some of the hills are actual volcanic centres or necks. The principal vents of eruption seem, however, to have lain near Stirling, where the volcanic series reach a thickness of about 6500 feet without the base being seen. The lavas are mostly andesites, some slaggy and some amygdaloidal, and some with fine tabular felspars ; there are also beds of fine tuff and thick accumulations of coarse agglomerate, one of the latter being as much as 1000 feet thick.

The Pentland Hills are the product of another great volcano, each ridge of the chain being the outcrop of a massive sheet of lava (see Fig. 61). The lowest lavas are diabases, and these are succeeded by andesites and felsitic tuffs, many of which are whitish or pale pink or yellow, while the andesites are dark red or purple. The maximum thickness of these rocks is about 7000 feet, and they are thickest near the northern end of the chain, where a large vent is recognisable, the hollow of this being filled with a "claystone" material, which seems to be mainly the compacted dust of felsitic lavas.

The Shetlands contain similar relics of volcanic action, not only of Lower but of Upper Old Red age.

Geography of the Period

The Silurian period was brought to a close by powerful earthments, which produced great geographical changes in the north-west of Europe. The greater part of the British region was elevated into dry land and formed part of a continent which must have had a considerable extension both to the west and to the north, and also to the north-east across the North Sea into the Scandinavian region. The general trend of the great flexures produced at this time is from W.S.W. to E.N.E., and it is supposed that the geoanticlines are the bases of parallel mountain ranges, and that the intervening troughs or synclines were occupied by great lakes, in which the Old Red Sandstones were accumulated.

Another result of the great lateral pressure which ridged up this continent and its mountain ranges was the compression and induration of all the rocks of which it consisted. The cleavage which was at this time developed in the Silurian and Ordovician rocks of Ireland, Scotland, North Wales, and the north of England, testifies to the

strength of the terrestrial disturbance, and it is due to the hardness and power of resistance thus imparted to them that they still stand out as upland districts at the present day.

The sea which covered so large a part of the British area in Silurian times was now contracted into a much smaller space, and only lay over the southern part of England, whence it stretched eastward through the north of France and Belgium. Westward it seems to have extended into Ireland (if the Glengariff grits are marine beds), but can only have covered a comparatively small area in the extreme south-western part of the country.

All the rest of Ireland appears to have been land, and was doubtless united to England and Scotland across the Irish Sea. Most of Northern England and North Wales was also land, but its southern coast-line was indented by a broad bay, in which the red sandstones and marls of Monmouth, Hereford, and Shropshire were accumulated. This bay probably narrowed toward the north-east, and may have passed into an estuary which received the waters of a large river draining the land in that direction. What I have called a bay is regarded by Sir A. Geikie as a lake, but I can see no reason for the existence of any land-barrier to the south of this bay, and imagine that it opened widely into the sea, in which the marine Devonians were being deposited, for the distance from Cardiff to the Quantock Hills is only about 22 miles.

To the east of this inlet there was land over the eastern Midlands, but it may not have been of any great breadth. Most probably it included a range of hills with a trend parallel to those on the north-west, and as rocks with Devonian fossils have been found below London, it is clear that the coast-line bent eastward or north-eastward through the eastern part of England.

The complete absence of marine fossils in the Lower Old Red of Scotland, the abundance of fish which could easily have adapted themselves to a freshwater habitat, and the frequency of plant remains, are facts which have led to the prevalent belief that the Old Red Sandstone of the North British region was accumulated in large lake basins like those which now exist in Africa and North America. Further, from the very different assemblages of fish which have been obtained from Forfar in the Caledonian area, and from Caithness in the Orcadian, Sir Archibald Geikie has inferred that these two areas were separate lake basins without any communication with one another.

On the other hand it is argued that if the thickness of the Lower Old Red be as great as is generally supposed, it is not likely that it was accumulated in long and narrow lakes. Further, it is admitted by Sir A. Geikie himself that the Red Sandstones must

originally have extended far beyond their present limits, both southward from the Orcadian and northward from the Caledonian area, so that "by the close of the period of the Old Red Sandstone a large part of the Highlands was buried under conglomerates and sandstones."[13] If this were so, it seems almost certain that the Orcadian and Caledonian water-basins must have been united, and very probable that they were parts of a large inland sea, the greater portion of which lay to the eastward, outside the present coast-line of Scotland. The Cheviot area may have been another inlet of this great lake.

It is possible, however, that the movement of subsidence was not uniform, but crept gradually northward, so that the area of the lake was extended by degrees in that direction.[14] On this theory the lowest beds in the Caledonian area are older than the lowest beds in Caithness, and the Forfar flags are older than the Caithness flags; this would account for the difference of the fish faunas.[a]

The existence of a tract of Lower Old Red in Cantyre, and of another on the coast of Antrim little more than 20 miles away, makes it very probable that Lake Caledonia was prolonged to the south-west, and included the Fintona district of Tyrone. From Lough Erne in Ireland to Stonehaven on the east coast of Scotland is a distance of about 280 miles, and it is evident that the lake extended much farther to the north-east, for there is no sign of a contracted breadth in Forfar; it may well have extended for another 70 or 80 miles, which would give it a total length of about 350 miles. This is about the length of Lake Michigan, which is very long for its width, this being nowhere much over 80 miles, and in most places much less.

Lake Orcadie, if it was a separate water-basin, would seem to have been even larger than Lake Caledonia, for its deposits even now extend from Loch Ness to the Shetlands, a distance of about 260 miles, while its width, from near Brora in Sutherland to Aberdour on the north coast of Aberdeen, is about 70 miles, and its original width must have been greater than this. As to its original length we have no means of forming a conception, for its north-eastern part lies below the North Sea.

The small tract in Donegal and that in the Firth of Lorne in Argyle may have been parts of another lake basin, of which only these small remnants are left.

During the formation of this great series of rocks volcanic activity was rife, and immense sheets of lava were poured over

[a] Dr. Traquair states that the Caledonian fishes—even those from high up in the series—are of an older type than those of the Orcadian series.

the country and interbedded with the sedimentary deposits, and all this time it is probable that the level of the inland waters was not very far above the level of the sea. Further elevation, however, ensued, and the excurrent rivers cut their channels deeper and deeper, till in course of time the waters of the lakes were completely drained off, just as the great Tertiary lakes of North America were drained by the excavation of the Colorado Cañon. The country would then present the aspect of a high and dry upland, formed of lofty hill ranges separated by immense sandy plains, the sites of the desiccated lakes ; through these plains the rivers may have run in deep and narrow channels, while on the mountain slopes piles of débris were prepared by the agencies of disintegration and detrition. It is, indeed, not unlikely that much of the material forming the conglomerates of the Upper Old Red Sandstone was originally prepared by subaërial agencies, and was only rearranged by the waters of the later epoch.

A reverse movement at length set in toward the end of what must be called the Devonian period ; portions of the old lake basins were again filled with water, the area of which widened and deepened as the land sank ; torrents washed in the detritus of the land, and the material thus collected became the conglomerates and sandstones of the Upper Old Red and Lower Carboniferous series.

References

[1a] See "Notes on the Palæozoic Rocks of Belgium," *Proc. Geol. Assoc.* vol. ix. p. 228.

[1] "The Devonian Rocks of Great Britain," *Rep. Brit. Assoc.* for 1889, and papers in *Trans. Roy. Geol. Soc.* Cornwall (1890), and *Proc. Som. Arch.* and *N. H. Soc.* 1900. See also the *Reports of the Progress of Geol. Survey*, 1892 to 1899.

[2] In the volumes of the Palæontological Society for the years 1889 to 1895.

[3] *Quart. Journ. Geol. Soc.* vol. xxii. p. 320 (1866).

[4] *Ibid.* vol. xxiii. p. 568.

[5] *Ibid.* vol. lii. p. 254, and vol. liii. p. 438.

[6] By Rev. W. S. Symonds. See his *Records of the Rocks*, p. 212 (Murray, 1872), which contains an excellent account of the whole district.

[7] See "Geology of the South Wales Coal-field," Parts I. and II. *Mem. Geol. Survey*, 1899 and 1900.

[8] See "Geology of the Southern Uplands of Scotland," *Mem. Geol. Survey.*

[9] See Professor Hull's paper, *Quart. Journ. Geol. Soc.* vol. xxxv. p. 703.

[10] *Quart. Journ. Geol. Soc.* vol. xlv. p. 369.

[11] *Ibid.* vol. xxxiv. p. 471.

[12] *Geol. Mag.* Dec. 3, vol. ii. p. 116.

[13] *The Scenery of Scotland*, second edition, p. 144.

[14] Consult a paper by Messrs. P. Macnair and J. Reid in *Geol. Mag.* Dec. 4, vol. iii. p. 106.

CHAPTER XI

The Carboniferous System

The materials for a history of this period are more ample than those available for the preceding periods. Carboniferous rocks occupy a larger part of the British Islands than the rocks of any other system, and in the search for coal they have also been more extensively studied and explored, so that it has become possible to trace the lateral changes which the component members of the system undergo, and to correlate the strata of different districts with much greater accuracy. In the British Islands and in the west of Europe generally, the Carboniferous system falls naturally into two divisions or series—a Lower or Carboniferous Limestone series and an Upper or Coal-measure series. In North America it is divisible in a similar manner, but the lower part is known as the Sub-carboniferous series, and the upper part only as the Carboniferous.

In England, France, and Belgium the Lower Carboniferous series consists almost entirely of marine deposits, and in most districts it is largely composed of limestone; while the Upper Carboniferous consists of a varied succession of sandstones, shales, clays, and coal-seams, which seem to have been deposited on the borders of a sinking land in estuaries and lagoons, where the water was sometimes saline and sometimes brackish or fresh. As each of these great series has in some places a thickness of from 9000 to 10,000 feet, and as the fauna of the one naturally differs much from the fauna of the other, it will be convenient to describe them separately and to take the lower series first.

A. The Lower Carboniferous Series

Range and Relation to Underlying Rocks

In England, Lower Carboniferous rocks occupy large tracts of the surface, and also have a wide subterranean extension. They

occur in the eastern part of Devonshire, and underlie a large area round Bristol, though partially concealed by beds of newer date; westward they extend under the Bristol Channel into South Wales, and across Carmarthen Bay into Pembroke; eastward they pass beneath newer rocks, and are believed to extend underneath Wiltshire, North Hampshire, and Surrey, forming part of the broad tract of Palæozoic rocks which is known to exist beneath the south-east of England. The Lower Carboniferous series thins out northward, and does not exist in the counties of Hereford, Worcester, Warwick, nor in South Staffordshire, but sets in again farther north in Shropshire, North Staffordshire, Derbyshire, and Leicestershire, and forms the core of the Pennine chain, from Derbyshire to Northumberland, and occupies large surface areas on either side; moreover, this series is supposed to underlie all the tracts covered by newer rocks in this part of the country, so that it is only really absent from the Lake District and the few other localities where older beds rise to the surface.

From Northumberland Lower Carboniferous beds spread into Scotland through the counties of Berwick and Haddington, and thence into the Lowland district, which they occupy entirely from side to side.

In Ireland they form more than half the rock-surface of the country, spreading over the whole central plain, from sea to sea, and stretching southward to the shores of Waterford and Cork.

In regard to superposition, it may be stated generally that where rocks of Upper Devonian or Upper Old Red Sandstone age are developed, the Carboniferous strata succeed in conformable sequence; but where these are absent, the Carboniferous rocks rest unconformably upon the older formations.

Life of the Period

The fauna of the Lower Carboniferous series is a rich one, both in genera and species. The following is a brief account of the prevailing genera and of new generic appearances—those with an asterisk not occurring in older rocks.

Foraminifera.—These become very abundant in the rocks of this period, and contribute largely to the formation of some of the limestones, the principal genera being *Saccamina*, *Fusulina*, *Trochammina*, *Valvulina*, and *Lagena*.

Anthozoa.—Of corals the most common genera are *Aulophyllum*,* *Lithostrotion*,* *Lonsdalea*,* *Phillipsastrea*, *Syringopora*, *Chætetes*, *Clisiophyllum*, *Michelinia*, *Zaphrentis*, *Amplexus*, and *Cyatho-*

phyllum. None of these genera survived to later times in Western Europe, but a few occur in the Permian of Asia.

Crustacea.—The only surviving genera of trilobites are *Phillipsia*, *Griffithides*, *Proetus*, *Cyphaspis*, and *Brachymetopus.* None are common, all are small, and all died out before the close of the period. Small Ostracoda are often abundant, belonging to the genera *Bairdia*, *Cypridina*, *Cypridinella*, and others. *Dithyrocaris* and other Phyllocarids also occur.

Echinoderma.—Crinoidea are abundant, and their remains often form a large part of the limestones. The chief genera are *Actinocrinus*,* *Platycrinus*, *Rhodocrinus*, *Cyathocrinus*, *Poteriocrinus*, *Amphoracrinus*,* and *Woodocrinus.** None of them, with the possible exception of *Cyathocrinus*, survived this period. Blastoidea now take the place of the Cystideans of the older Palæozoic rocks, the commoner genera being *Granatocrinus*, *Codaster*, and *Orophocrinus.* Of Echinoidea there are *Archæocidaris*, *Palæchinus*, and *Melonites.*

Brachiopoda.—Most of the Devonian genera survive, such as *Orbiculoidea*, *Productus*, *Spirifer*, *Rhynchonella*, *Athyris*, *Chonetes*, *Orthis*, and *Terebratula*, but there are no common distinctive Carboniferous genera.

Lamellibranchia.—The following are some of the commoner genera, those with an asterisk making their first appearance: *Aviculopecten*, *Crenipecten*, *Posidoniella*,* *Parallelodon*, *Conocardium*, *Myalina*, *Schizodus*,* *Leptodomus* (*Protoschizodus*), *Edmondia*, *Cardiomorpha*, *Pleurophorus*, *Cypricardella*,* and *Sanguinolites.**

Gastropoda.—Most of the Devonian genera continue, and the commoner are: *Pleurotomaria*, *Murchisonia*, *Bellerophon*, *Euomphalus*, *Straparollus*, *Naticopsis*, *Capulus*, *Loxonema*, *Macrochilina*, and *Turbonitella*, but very few of these survive the close of the Carboniferous period.

Cephalopoda.—The following are some of the genera which occur:—Of Nautiloidea there are *Orthoceras*, *Actinoceras*, *Cyrtoceras*, *Discites*, *Poterioceras*, *Temnochilus*,* *Cœlonautilus*,* *Vestinautilus*,* *Stroboceras*,* and of Ammonidea the following genera belonging to the Goniatitidæ, *Brancoceras*, *Pericyclus*,* *Glyphioceras*, *Nomismoceras*,* *Dimorphoceras*,* *Prolecanites*,* *Pronorites.**

Pisces.—Remains of fish are very numerous, and a long list of names founded on the teeth and spines of fish might be given, but the following are known from more complete remains:—*Eurynotus*, *Rhizodus*, *Holyptchius*, *Megalichthys*, *Cœlacanthus*, *Platysomus.* Many of the Carboniferous fish were Elasmobranchs, and most of the remainder are Teleostomi of the Crossopterygian order.

A remarkable feature in the distribution of the marine fauna is the persistence of the same species and groups of species through-

out such a great thickness of strata. A few species are indeed confined to the lowermost beds, and a few to the highest marine beds—to beds, in fact, which were formed when the physical conditions were undergoing a change, and when the forms would necessarily be more liable to variation ; a few other species—those, namely, which were the chief contributors to the formation of the limestones—are naturally most abundant in those limestone masses ; but by far the larger number of species have a very great

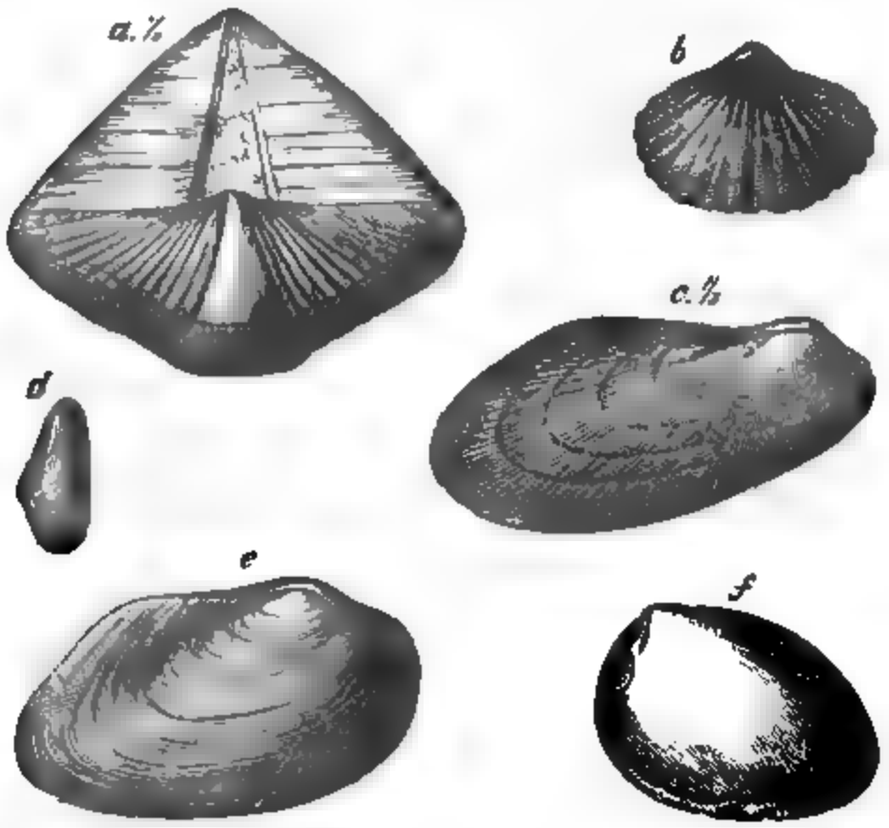

Fig. 63.—GROUP OF LOWER CARBONIFEROUS FOSSILS.

a. Spirifer cuspidatus.
b. Rhynchonella pleurodon.
c. Avicula damnoniensis.
d. Modiola Macadami.
e. Cucullea Hardingi.
f. Curtonotus elegans.

vertical range, many of them extending from top to bottom of the marine series, and some even appearing in the Upper Carboniferous series.

We are thus presented with the unique phenonomen of the same species of fossils occurring throughout a thickness of from ten to fourteen thousand feet of strata—a fact which testifies to the great uniformity of the physical conditions which prevailed during the whole period. When we compare this state of things with the distribution of species in earlier or in later periods, we cannot

fail to be struck with the singularity of the Carboniferous period in this respect. It would appear as if there was then a great pause in the evolutional history of the organic world—a time when the changes in the surrounding physical conditions were so slight and gradual that the causes of variation and differentiation were at a minimum, and the forms of life became as it were stereotyped for a time.

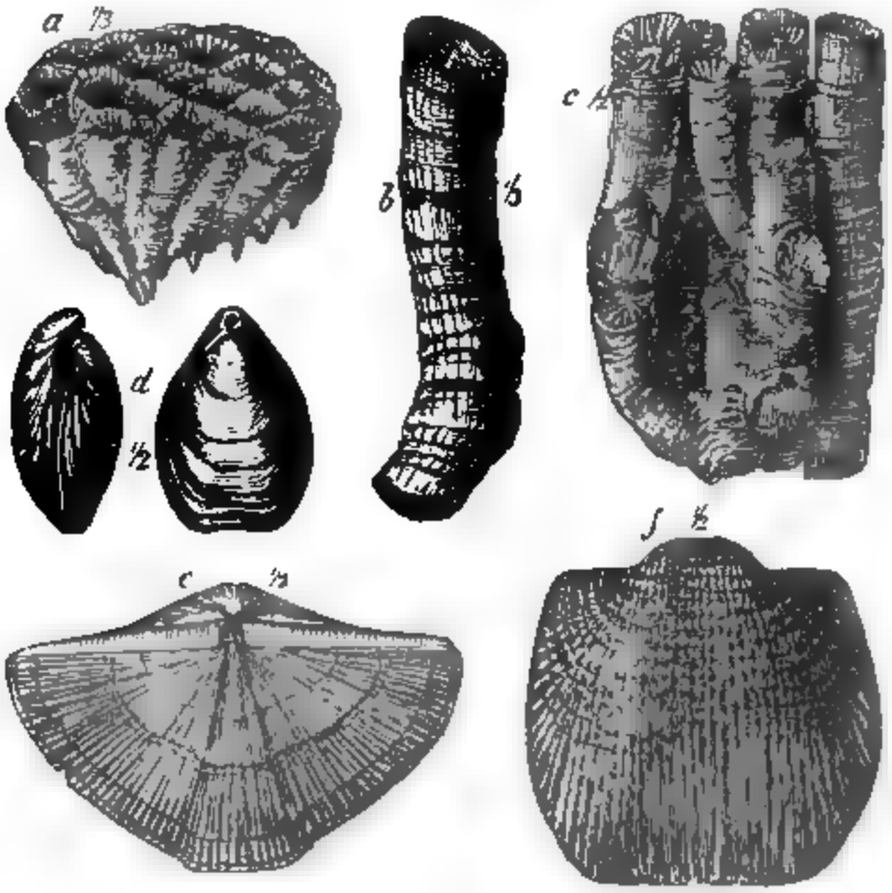

Fig. 64.—GROUP OF LOWER CARBONIFEROUS FOSSILS.

a. Michelinia favosa.
b. Amplexus coralloides.
c. Lithostrotion affine.
d. Terebratula hastata.
e. Spirifer striatus.
f. Productus semireticulatus.

So far as researches have hitherto been carried, very few species appear to be restricted to special horizons in the Lower Carboniferous series. Some are of course much more common in the limestones than in shales and sandstones, and *vice versa*. All the corals, for instance, are more abundant in the limestones; some Lamellibranchs, on the other hand, are rare in limestone. Dr. W. Hind remarks that he has never found *Nucula*, *Nuculana*, or *Ctenodonta* in the white and gray limestones, yet they range

throughout the whole series where mechanical deposits prevail, and evidently preferred muddy bottoms. Thus *Nucula gibbosa* and *N. attenuata* occur in the Calciferous sandstones of Scotland, in the Bernician of Northumberland, and in the Lower Coal-measures of Yorkshire and Derbyshire.

The following species appear to be specially characteristic of the lowest fossiliferous beds, *i.e.* the lower shales of Bristol and South

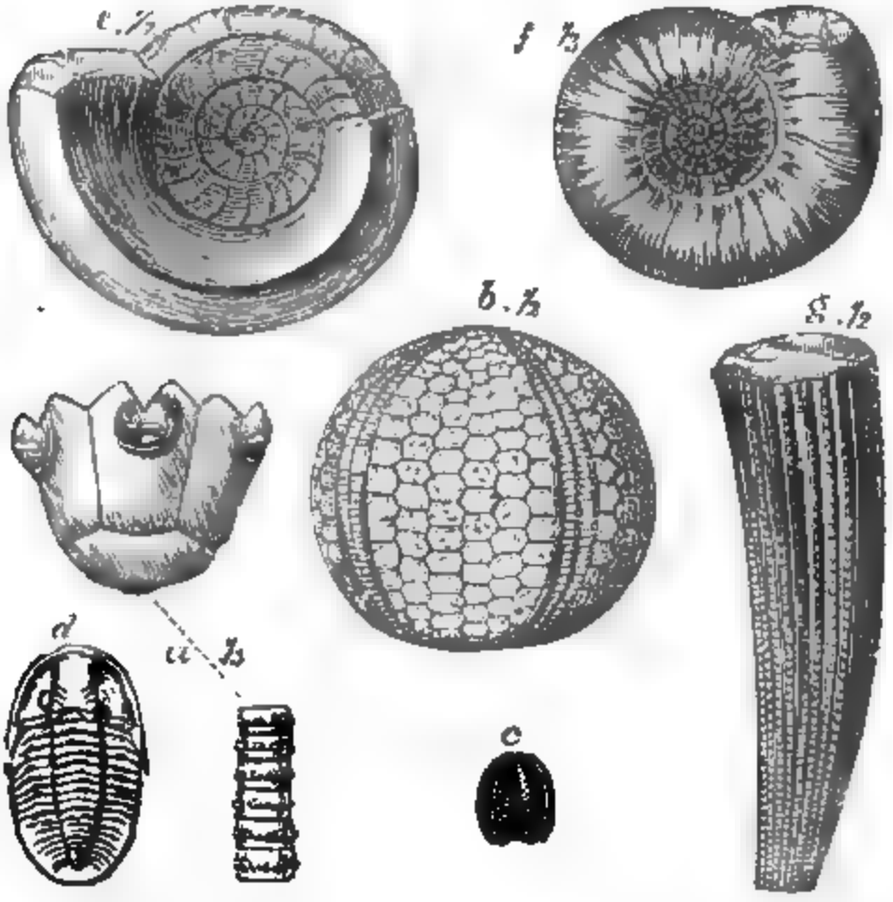

Fig. 65.—GROUP OF LOWER CARBONIFEROUS FOSSILS.

a. Platycrinus lævis.
b. Palæchinus gigas.
c. Granatocrinus ellipticus.
d. Phillipsia pustulosa.
e. Cælonautilus cariniferus.
f. Gastrioceras Listeri.
g. Orthoceras Gesneri.

Wales, the Tuedian of the north, the Calciferous sandstone of Scotland and Northern Ireland, and the Coomhola grits of Cork and Kerry :[a]—

Lepidodendron veltheimianum, Leperditia Okeni, Chonetes laguessiana,† *Orthotetes crenistria, Modiola Macadami,*† *Myalina crassa, Schizodus*

[a] In this and the following lists those species to which a dagger is affixed are specially characteristic of the Lower Carboniferous series.

pentlandicus (*S. Salteri*), *Protoschizodus obliquus* (? *Curtonotus elegans*), and *Sanguinolites abdensis*.

The following species prevail in the lower limestones of Bristol and of Central Ireland :—

Michelinia favosa,† *Lithostrotion junceum*,† *L. affinis*,† *Chaetetes tumidus*, *Fenestella flabellata*, *Cyriopora gracilis*, *Platycrinus lævis*, *Poteriocrinus crassus*, *Rhynchonella pleurodon*,† *Spirifer cuspidatus*,† *S. striatus*,† *Cardiomorpha oblonga*, *Edmondia sulcata*, *Conocardium hibernicum*, *Aviculopecten granosus*, *Nautilus triangulatus*, and *N. dorsalis*.

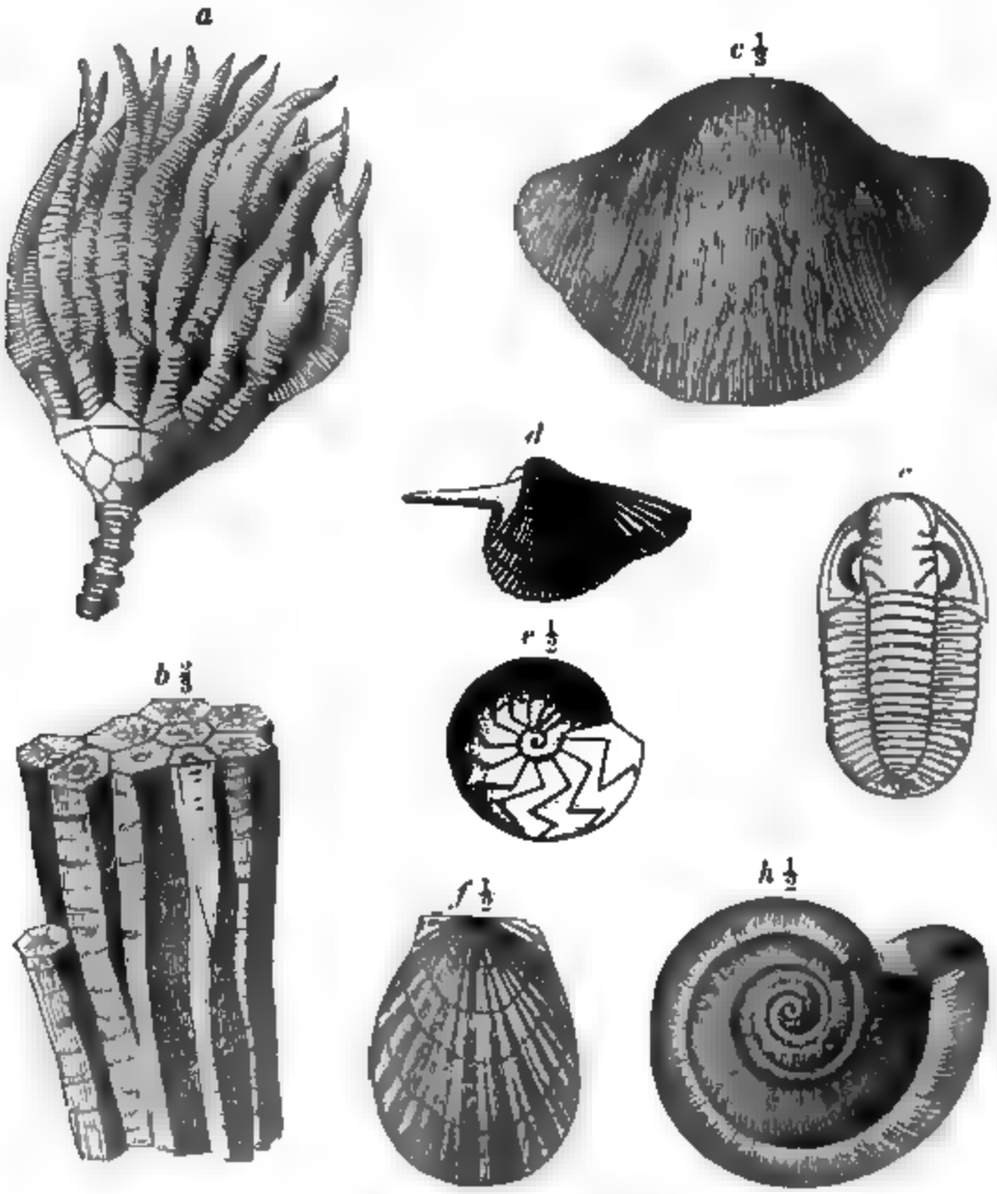

Fig. 66.—GROUP OF LOWER CARBONIFEROUS FOSSILS.

a. Woodocrinus macrodactylus.
b. Lithostrotion basaltiforme.
c. Productus giganteus.
d. Conocardium aliforme.
e. Glyphioceras sphæricum.
f. Aviculopecten sublobatus.
g. Phillipsia derbiensis.
h. Euomphalus pentagonalis.

In the higher limestones of the same districts the following are common species :—

Lithostrotion striatum, L. irregulare, L. Portlocki, Cyathophyllum regium, Lonsdalea floriformis, Productus giganteus,† P. cora,† P. longispinus, Terebratula hastata,† Euomphalus nodosus, Bellerophon apertus.

Besides those above mentioned the following are common and characteristic Lower Carboniferous forms :—

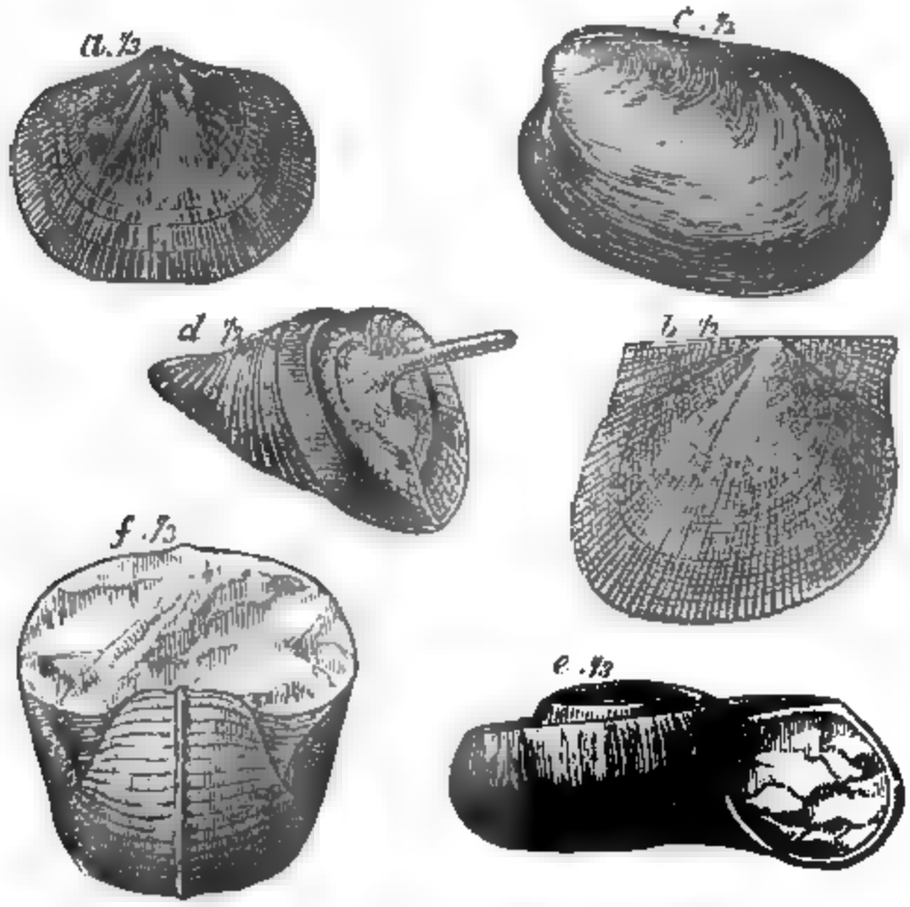

Fig. 67. GROUP OF LOWER CARBONIFEROUS FOSSILS.

a. Orthis resupinata.
b. Aviculopecten papyraceus.
c. Cardiomorpha oblonga.
d. Conocardium hibernicum.
e. Euomphalus pentagonalis.
f. Bellerophon tangentialis.

Foraminifera. Saccamina Carteri, Trochammina incerta.
Actinozoa. Amplexus coralloides,† Lithostrotion basaltiforme, Syringopora reticulata, Zaphrentis cylindrica.
Echinoderma. Granatocrinus derbiensis,† Codaster trilobatus, Actinocrinus amphora,† A. triacontodactylus, Woodocrinus macrodactylus, Cyathocrinus lævis, Palæchinus sphæricus, P. gigas.
Brachiopoda. Athyris ambigua, A. Royssi, Spirifer glaber,† Rhynchonella acuminata,† Productus scabriculus, P. semireticulatus,† Terebratula sacculus, Orthis resupinata, O. Michelini.

Lamellibranchia. Conocardium aliforme, C. hibernicum, Cardiomorpha orbicularis, Aviculopecten sublobatus.

Gastropoda. Euomphalus pentagonalis,† Naticopsis plicistria, Pleurotomaria carinata (flammigera), Bellerophon Urei, B. tangentialis, Conularia quadrisulcata, Macrochilus ovalis.

Cephalopoda. Cœlonautilus cariniferus,† Gastrioceras Listeri,† Glyphioceras sphæricus, Cyrtoceras Gesneri, Orthoceras undulatum.

Crustacea. Phillipsia pustulosa, P. derbiensis,† Griffithides globiceps, Brachymetopus ouralicus, Dithyrocaris Colei.

Pisces. Cladodus striatus, Cochliodus contortus, Ctenacanthus major, Eurynotus crenatus, Orodus ramosus, Petalodus acuminatus, Psammodus porosus.

Stratigraphy

1. *South-western Area*

Under this head will be included a brief description of the Lower Carboniferous rocks in the counties of Devon, Somerset, Gloucester, Monmouth, Glamorgan, and Pembroke. In these districts the rocks are folded into a set of troughs and basins separated by anticlinal ridges of Devonian and Old Red Sandstone, but in Gloucester and Somerset the Palæozoic rocks are partially concealed by a greater or less thickness of Neozoic strata (Trias and Jurassic), and are only exposed here and there in tracts from which these younger strata have been removed.

In Devon, Carboniferous rocks occupy a broad trough between the two tracts of Devonian described in the last chapter. The greater part of this trough is occupied by beds of Upper Carboniferous age, but a lower series can be separated both on the northern and southern border (see map, Fig. 56). The next appearance of this series is in the Mendip Hills, where it has a normal calcareous facies. These hills form the southern border of the Somerset and Bristol coal-field, which is an irregular basin-shaped area nearly surrounded by outcrops of the Carboniferous limestone.

Crossing the Severn we find a tract of Lower Carboniferous rocks in the neighbourhood of Chepstow, which stretches northward and is united to the periclinal area that encloses the coal-field of the Forest of Dean, a perfect example of a basin-shaped area.

Passing westward, and crossing the tract of Silurian and Old Red Sandstone which lies on either side of the river Usk, we come to the great coal-field of South Wales. Here the Carboniferous rocks occupy a long basin or trough-shaped area, which extends from Pontypool in Monmouthshire to Carmarthen Bay, with a narrow prolongation across this bay, through Pembrokeshire to St. Bride's Bay. The area east of Carmarthen Bay is traversed by a remarkable

CORRELATION TABLE OF THE CARBONIFEROUS SYSTEM

	Bristol and South Wales.	South and Central Ireland	Stafford, Derby, and South Lancashire.	North Riding of Yorkshire.	Durham and Northumberland.	Scotland.
Upper Carboniferous.	Upper Coal-measures, 2000 to 3000 feet.	Up. C.M, absent.	Upper Coal-measures, 2000 feet.	Coal-measures removed by denudation.	Upper C. M. †	Upper Coal-meas., 900 feet.
	Pennant grits, 1000 to 3000 feet.	Coal-measures, 1300 to 2000 feet.	Middle Coal-measures, 2000 to 3000 feet.		Middle Coal-measures, 2000 feet.	† Absent.
	Lower Coal-measures, 2000 to 850 feet.		Lower Coal-measures, 1000 to 2000 feet.		Lower C. M. and Millstone g., 500 ft.	Lower Coal-meas., 1300 feet.
	Millstone grit, 1000 to 80 feet.	Flagstone group, 500 feet.	Millstone grits, 400 to 3500 feet.	Millstone grits, 3000 to 600 feet.	Fellton division, 500 to 1200 feet.	Millstone grit, 400.
	Shales.	Shales with Posidoniella, 600 feet.	Pendleside group, 1600 feet.	Chert beds, 160 ft.	Calcareous division down to Dun. limestone, 2000 feet.	Upper limestones and Edge coal group, 1100 feet.
Lower Carboniferous.	Upper limestone group, 1500 to 2000 feet.	Upper and Middle limestones, 1900 feet.	Clitheroe and Cracoe limestones, over 3000 feet.	Yoredale beds, 800 to 1000 feet.	Carbonaceous division 2000 feet.	Lower limestones, 400 feet.
	Lower limestones, 550 to 1300 feet.	Lower limestones, 800 feet.		Great Scar limestones, 800 to 1600 feet.	Fell sandstones, 1000 feet.	Oil shale group, 3700 feet.
	Limestone shale.	Lime-stone shale and basal beds, 1100 feet.	Base not seen.	Sandstones and conglomerates, 100 to 1000 feet.	Lower Tuedian, 1500 feet.	Granton and Hailes sandstones, 3400 feet.
						Ballagan beds, 1200 feet.
						Red sandstone group, 1200 feet.

anticlinal axis, which divides the basin into a northern and southern trough.

The strata composing the Carboniferous series are thickest in the south-eastern part of this area, and diminish partly by thinning out, and partly by overlap towards the west and north. It will be convenient to describe the succession found in the Mendip and Bristol district first as exhibiting the typical facies with which the more western tracts may be compared, and finally to give some account of the Culm-measures in Devon and Cornwall.

In the Mendip Hills the total thickness of the limestone series is believed to be nearly 4000 feet, and near Bristol it is nearly 2400. No definite base line has yet been fixed, for the Upper Old Red Sandstone passes up by the intercalation of red, green, and gray shales into dark gray shales, which contain Carboniferous fossils. The whole series is divisible into a lower limestone with shales at the base, and an upper limestone with oolitic limestones at the base. These divisions seem to vary in thickness, as shown in the following table, which is compiled from papers by Mr. Wethered and Professor C. L. Morgan.

	Mendip Hills.	Clifton.	Wickwar.
Sandy limestones and shales	?200	400	300
Upper limestone (Lithostrotion beds)	?1800	1000	530
Oolitic limestones	250	100	520
Lower limestone (Encrinital beds)	1300	550	
Shales and thin limestones	350	320	320
	3900	2370	1670

The basal shales are well exposed in the gorge of the Avon at Clifton, and they include near the base a remarkable bed, which is crowded with the remains of fish in the shape of teeth and bones, whence it is known as the "bone bed." The shales also yield *Rhynchonella pleurodon*, *Athyris Roysii*, *Poteriocrinus crassus*, and other fossils. The thin limestone bands are largely made up of the carapaces of Ostracoda and of Corals and Bryozoa, among which *Monticulipora tumida* is common.

The Lower limestones above are generally of a dark gray colour, and near Bristol they are almost black, and are known as the black-rock limestone. Their principal constituents are crinoid stems, with Ostracoda, Bryozoa, and small organisms with a fibrous structure, which are named *Mitcheldeanea*, and are believed to be Hydrocoral-lines. From the abundance of the remains of crinoids these are known as the Encrinital beds.

Passing over the oolitic limestones, which are chiefly remarkable in being oolitic, we come to the mass of the Upper limestone, at the

Fig. 68.—DIAGRAMMATIC SECTION FROM THE MENDIP HILLS SOUTHWARD FOR ABOUT 4 MILES.

Neozoic { l. Lias limestones. r. Rhætic beds. k. Keuper marls. c. Dolomitic conglomerate.

Palæozoic { 5. Coal-measures. 4. Millstone grit. 3. Carboniferous limestones. 2. Lower limestone shale. 1. Old Red Sandstone.

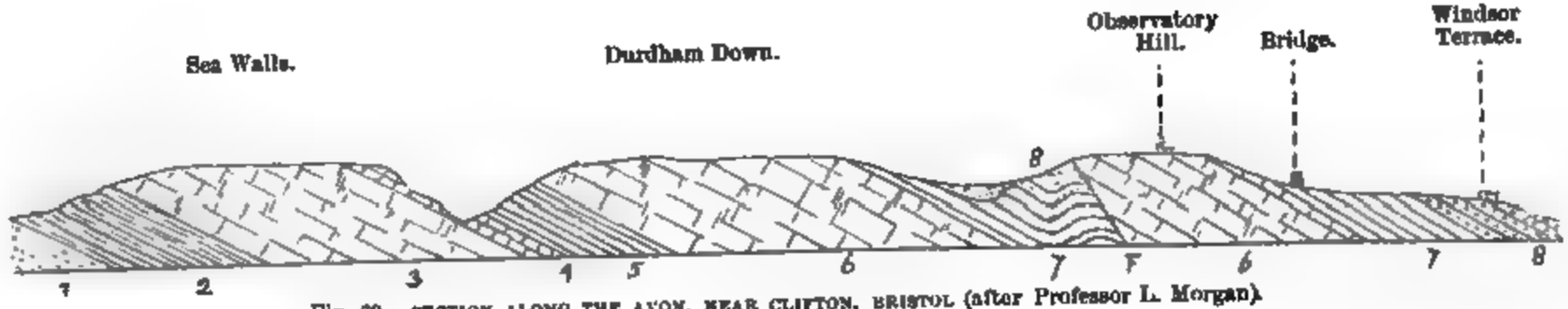

Fig. 69.—SECTION ALONG THE AVON, NEAR CLIFTON, BRISTOL (after Professor L. Morgan).

8. Millstone grit.
7. Upper shales.
6. Upper limestone.
5. Middle shales.
4. Gully oolite.
3. Lower limestone.
2. Lower shales.
1. Old Red Sandstone.

base of which are some dark shales, sometimes called the middle Upper shales. The limestones are bluish gray, and consist principally of Foraminifera and Calcispheres, with a smaller proportion of broken shells, crinoids, and corals. Of larger organisms *Lithostrotion* and *Syringopora* are common with species of *Productus* and *Spirifer*. The highest beds are shaly and sandy limestones passing up into calcareous grits with 80 per cent of siliceous matter. At Wickwar, near the northern end of the Bristol coal-field, the Limestone series is reduced to a thickness of 1670 feet, and still farther north in the Forest of Dean it is reduced to about 600 feet, and even less on the northern border.

At the eastern end of the South Welsh coal-field near Newport the limestones are still thinner, being only from 300 to 350 feet, according to recent measurements by the Geological Survey; but as they are followed westward along the southern border of the coal-field they thicken again till they reach 1000 feet, and are

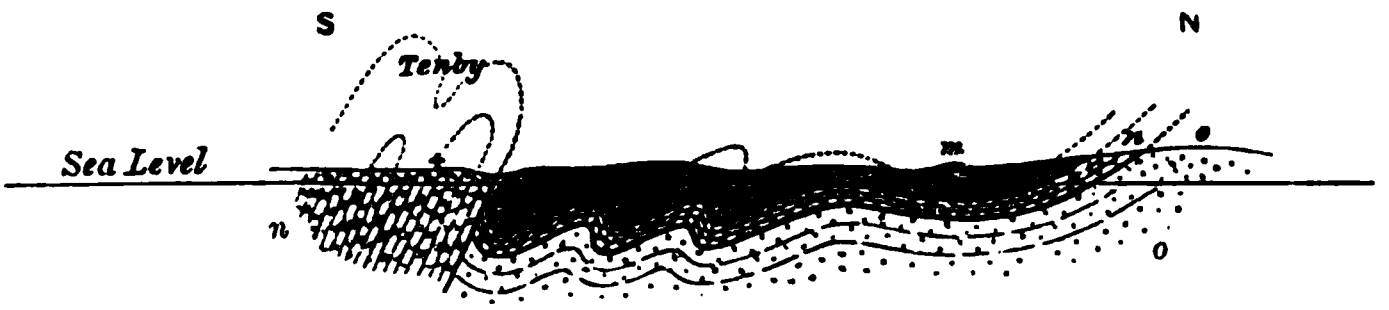

Fig. 70.—SECTION ACROSS THE PEMBROKESHIRE COAL-FIELD (Professor Hull).

m. Coal-measures. *n*. Carboniferous limestone.
o. Lower shales and Old Red Sandstone.

divisible into a lower limestone (200 to 300 feet) and an upper limestone (of 700 to 800 feet).

In Pembrokeshire the thickness is again reduced, but good sections of the whole series are exposed near Tenby and on the south side of Milford Haven. Near Tenby the limestone has an apparent thickness of over 1000 feet, but this is probably due to repetition of the beds by flexures, as shown in Fig. 70, and the real thickness is probably not more than 500 feet. Below it are about 400 feet of shales and thin limestones. In West Angle Bay (Milford Haven) the shales are thicker (550 feet), and are underlain by a set of gray shales and sandstones which contain Upper Devonian fossils of the Marwood and Pilton beds, such as *Avicula damnoniensis, Cucullæa trapezium, Curtonotus elegans.*[1]

Devonshire.—The delimitation of the Upper Devonian and Lower Carboniferous rocks in Devonshire has not yet been worked out. The junction-beds have not been specially described since Mr. Salter compared them with those of Pembrokeshire in 1863,

but his opinion was that the Pilton beds included the equivalent of the Lower limestone shale. He says, "Nearer Barnstaple these Pilton beds begin to trough in small patches of a barren, softer slate, which is only seen well developed south of Pilton, and occupying the lower ground east and west of Barnstaple." In these soft slates the prevalent fossils are *Phillipsia seminifera*, *Spirifer bisulcatus*, *S. laminosus*, *S. cuspidatus*, *Productus Martini*, *Orthis Michelini*, and other exclusively Carboniferous species. Mr. Whidborne informs me that similar shales occur at Fremington.

They are succeeded by the series of beds which occupy the broad Carboniferous basin of Devonshire and are known as the Culm-measures (see map, p. 181). This tract varies in breadth from 20 to 30 miles, and is exposed for a length of about 50 miles, passing eastward with undiminished width beneath the Neozoic rocks, so that this great basin or trough probably continues to extend eastward for many miles though concealed by younger rocks. The rocks found in the exposed portion are divided by Mr. Ussher as follows,[2] but the two upper divisions appear to be of Upper Carboniferous age :—

Upper.—Hard bedded gray grits with shaly layers.
Middle.—Hard thick-bedded sandstones, generally light gray or green, with fine grits, mudstones, and shales.
Lower.—Dark gray shales and mudstones with bands of radiolarian chert and lenticular beds of gray limestone.

The beds are everywhere intensely folded and flexured, so that no accurate estimate of thickness can be made, but some exposures of the chert beds alone show from 100 to 150 feet of them, and the whole of the Lower Culm beds may be from 1000 to 1500 feet. Their outcrop on the north is continuous, but of varying width, and on the south they form a continuous band round the northern half of the Dartmoor granite, whence they stretch westward by Launceston to the coast at Boscastle.

The rocks which form the Lower Culm are in most places so folded and faulted that it is difficult to determine the succession of their component beds. Thus Mr. Ussher, who has surveyed the greater part of the area, still feels uncertain whether the Chert beds occupy a definite horizon. Messrs. Hinde and Fox, however, who have specially studied these beds, think that the following is the usual order of succession in descending order : [3]—

Dark shales without fossils.
Radiolarian cherts and shales (Coddon Hill beds).
Brown and red shales of Waddon Barton.
Black shales and limestones with *Posidonomya*.

Along the northern border there seems to be a gradual passage from the Barnstaple beds into a set of black carbonaceous shales and thin limestones containing several species of *Posidonomya* (*P. Becheri*, *P. lateralis*, etc.), with the Goniatites, *Glyphioceras sphæricum*, *G. crenistria*, and *G. striatum*.

The Waddon Barton beds are at present only known in the country east of Dartmoor and near Bampton in North Devon ; they are characterised by the abundance of *Glyphioceras spirale ;* they also contain *Orthoceras striolatum*, *Avicula lepida*, *Spirifer Urei*, *Posidonomya Becheri*, and four species of *Phillipsia*, three of which occur also in the Chert beds.[a]

The Coddon Hill beds consist of gray and black cherts in thin but regular beds, often interleaved with hard black shales. Radiolaria are abundant, and have been referred to no less than twenty-three genera by Messrs. Hinde and Fox (*op. cit.*). These beds contain also *Prolecanites mixolobus*, *Nomismoceros spirorbis*, several species of *Phillipsia* and *Griffithides*, many stems of *Cyathocrinus*, *Productus concentricus*, *Orthotetes crenistria*, and other brachiopods.

Near Westleigh and Canonsleigh there are ridges formed of bluish limestone with intercalated cherty beds, which seem to be near the horizon of the Coddon Hill beds, for they contain the same two *Goniatites* and the well-known Carboniferous coral *Michelinia favosa*.

2. *Derby, Stafford, and North Wales*

It will be seen from the map, Fig. 71, that the Lower Carboniferous rocks occupy a large part of Derbyshire and a small area in the north of Staffordshire, and that with the overlying Millstone grit they form the southern part of the great Pennine range of hills which is often called "the backbone of England."

The general structure of this central district is shown in Fig. 73, the strata being bent up into a broad irregular dome or periclinal ellipse, so that the lowest beds are found in the centre of the area, from which they dip decidedly to the east and west, and more gently to the north. The length of this area from Ashbourne to the head of Derwentdale is about 30 miles, and its width from east to west between Buxton and Bakewell about 16 miles.

The Carboniferous limestones and shales pass both eastward and westward beneath the basins in which the Coal-measures lie, and on the western side they rise again to the surface in the counties of Denbigh and Flint. Whether there is a similar uprise of the

[a] These fossils were found by the late Mr. J. E. Lee and described by Dr H. Woodward, who notices the similarity of the fauna to that of the Culm at Herborn in Germany. See *Geol. Mag.* Dec. 3, vol. i. p. 538.

GEOLOGICAL MAP OF THE NORTHERN PART OF ENGLAND

Fig. 71

Lower Carboniferous series on the eastern side we do not know because the eastern part of the Nottingham coal-field is concealed beneath newer rocks ; there is, however, a high probability that it is a complete basin.

Derbyshire.—The general succession of this series in Derbyshire is as follows :—

	Feet.
4. Shales and thin beds of black limestone	400
3. Gray and white limestones, some parts containing layers of chert.	640
2. Massive white limestones with interbedded lava-flows (toadstones)	900
1. Dark limestones with toadstones and ash beds . . seen for	600
	2540

The actual base is nowhere exposed, and consequently the total thickness of the series is unknown, but it is doubtful whether it exceeds 3000 feet even in the centre of the area. The whole of the series thins out to the south-west before reaching the South Staffordshire coal-field, but continues toward the south-east beneath the small Leicestershire coal-field, and wraps round the Pre-Cambrian rocks of Charnwood Forest.

The limestones which compose the "Mountain limestone" of Derbyshire vary much in lithological character,[4] some consisting mainly of broken fragments of crinoids and shells, others of corals and coral débris, and others being compact and foraminiferal, while in many parts the organisms have been obscured or destroyed by the chemical changes of marmorisation or dolomitisation.

Mr. Bemrose remarks that corals are frequent in some of the lower massive beds, and that remains of crinoids are often numerous. *Productus giganteus* and *Chonetes papilionacea* occur throughout, and one bed near the top consists almost entirely of the *Productus*. The recent efforts of Messrs. W. Hind and J. A. Howe to ascertain whether there is any zonal distribution of the fossils have failed because of the scarcity of fossils, except in the upper 200 feet, all the rich fossil horizons being near the top of the gray limestone. They think it probable that this rarity of fossils below is due to the chemical changes which the rock has undergone.

The gray limestones (No. 3) are generally thin-bedded, with partings of shale, and often contain layers and nodules of chert ; the layers of chert have undulating surfaces and are sometimes connected with nodular masses of chert ; the nodules are sometimes scattered, and sometimes in planes parallel to the bedding, like flints in the Chalk. These cherts are probably like those described by Dr. G. J. Hinde, from Yorkshire and North Wales, and found

to consist largely of sponge spicules.[5] The upper limestones are best exposed at Castleton and round Buxton, and are also well seen at Crich Hill, south-east of Matlock, where the limestone is brought up as an inlier between two faults (see Fig. 72).

At the top of this limestone is a bed of rolled shells and limestone pebbles with occasional quartz pebbles; it was first found at Castleton, but has since been traced by Dr. W. Hind through the whole of Derbyshire and North Staffordshire. It contains many brachiopods, trilobites, and teeth of *Psammodus*, *Psephodus*, etc., and seems to have formed a beach which retreated from north to south before the overlying shales were laid down upon it.

In the memoirs of the Geological Survey it is stated that the Carboniferous limestone is overlain by a representative of the Yoredale beds of Yorkshire, and this is said to consist of two parts, thus :--

Yoredale beds { Shales with thin beds of sandstone.
Shales with thin beds of limestone.

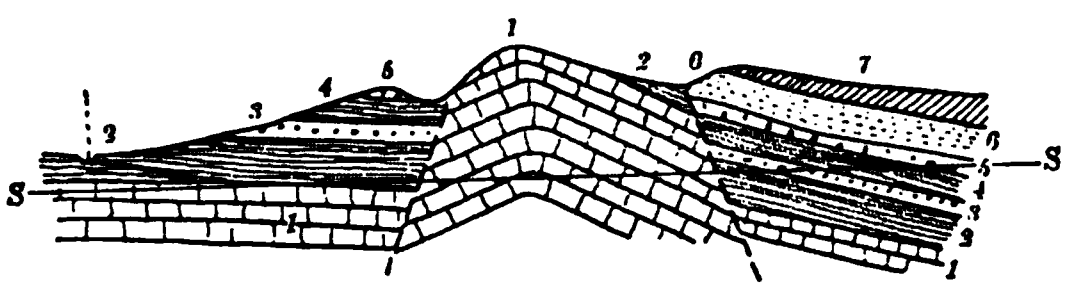

Fig. 72.—SECTION THROUGH CRICH HILL, DERBYSHIRE.

7. Coal-measures.
3 to 6. Millstone grits.
2. Yoredale shale.
1. Carboniferous limestone.

This correlation, however, is doubtful. The black shales and limestones, which contain *Productus giganteus* and *Chonetes papilionacea*, only occur in the southern parts of Derbyshire, and are absent near Castleton, where black shales with a different fauna rest directly on the gray and white limestones. These, with the overlying sandstones and shales, are probably to be regarded as Upper Carboniferous.

North Wales.—Passing westward beneath the plains of Cheshire, the Carboniferous rocks emerge again in Shropshire, Denbigh, and Flint; the whole of the lower series rises from below Millstone grit, and forms a long narrow tract running from the Bala fault in the valley of the Vyrnwy northward to the coast at Prestatyn. Along this tract the outcrop of the limestones forms a bold range of hills with a terraced escarpment on the western side. They are brought in again along the western side of the Clwyd valley by a powerful fault running along that valley under the Trias, and thence the limestones skirt the coast to Llandudno, where they form the promontories of the Great and Little Orme's Head (see map, Fig. 14). Small detached tracts of the limestone

occur on each side of the Menai Straits, and in the centre of the Isle of Anglesey.

The Lower Carboniferous series is thickest in the northern part of this district, but continues in strong force to where it is cut off by the great Bala fault south of Oswestry; when it comes in again in Central Shropshire it has thinned to less than 100 feet. The following subdivisions were made by Mr. G. H. Morton and are generally accepted :—

Flintshire.	Feet.
Cherty sandstone .	250
Black limestones .	200
Gray limestones .	500
White limestones .	600
Brown limestones .	400
Basement beds .	500 to 0
	2450

Llangollen and Oswestry.	Feet.
Cherty sandstone .	200
Flaggy limestones .	300
Gray limestones .	300
White limestones .	420
Brown limestones .	480
	1700

Near Prestatyn on the coast of Flint the whole series is estimated to be 2500 feet thick, but 500 feet of this consists of red sandstone with a basal conglomerate of quartz pebbles resting unconformably upon the Silurian. These beds thin out southward, and three miles east of Ffernant they are overlapped by the limestones, and the basement bed is then a brecciated limestone with some layers of pebbly sandstone.

The three lower limestone groups exhibit the same characters throughout their range, but the black limestone is replaced toward the south by flaggy limestone containing small quartz pebbles and layers of grit. The brown limestone does not yield many fossils, but *Productus conioides* is restricted to it. The white beds yield a larger number, including *Bellerophon costatus*, *Edmondia sulcata*, *Productus cora*, *Spirifer lineatus*, *Rhynchonella pleurodon*, and some corals. Most of the species in the white limestones range up into the gray, but the following are more common in the latter :— *Productus giganteus*, *P. latissimus*, *Athyris Roysii*, *Spirifer bisulcatus*, *Chonetes laguessiana*, *Orthis resupinata*, and *Lithostrotion irregulare*.

The black limestone of Halkin contains *Productus giganteus* and many of the fossils above mentioned, and this limestone is doubtless equivalent to the flaggy limestones of Llangollen and Oswestry; but the black limestone of Prestatyn yields *Posidonomya Becheri*, *P. Gibsoni*, *Avicula papyraceus*, and *Goniatites bilinguis*, which indicate a higher horizon (Pendleside group).

The cherty sandstone consists of compact, fine-grained brown sandstones, each bed having a medial band of gray or black chert, and the beds are sometimes divided by layers of white shale, which

contain *Chonetes laguessiana* and *Productus longispinus*. The cherts are full of sponge spicules, and only differ from some beds in the limestone of Yorkshire in having a sandy admixture instead of a calcareous one. This sandstone is sometimes regarded as part of the Millstone grit, but seems by its fossils more closely connected with the Limestone series.

3. *Lancashire and North Pennine Area*

The Lower Carboniferous series is brought up again from beneath the Millstone grits in Lancashire and West Yorkshire (see map, Fig. 71) by an anticlinal flexure, which runs in a north-easterly direction from near Blackburn by Clitheroe to Skipton, with a more northerly prolongation by Cracoe across Wharfedale by Burnsall. From these places this division of the system spreads northward, and occupies a large irregular tract of ground varying from 15 to 30 miles in width, through Yorkshire, Durham, and the eastern parts of Westmoreland and Cumberland, with off-sets which pass round the southern and northern borders of the Lake District. From Skipton on the south to Alston on the north is a distance of about 60 miles.

The rocks of this large area present two different facies—one in the south-west, which has been called the Clitheroe type, and the other to the north, which is known as the Yoredale type. Moreover, the transition from one to the other is rapid, and coincides closely with the line of the Craven fault, which runs obliquely across the area from near Kirkby-Lonsdale by Ingleton, Stainforth, and Linton. South of this line the beds attain a great thickness, and their base is nowhere exposed; north of it the base is exposed in several places, resting on a floor of upturned Ordovician and Silurian rocks, but the limestones are comparatively thin, and the overlying shales completely thin out. The following is a comparative view of the succession in the two districts, from the Millstone grit downwards, to show which beds are included in the Lower Carboniferous series according to Dr. W. Hind's classification:—

	Clitheroe District.	Feet.	Ingleton and Grassington.	Feet.
Upper Carboniferous.	Millstone grit (4th grit).		Millstone grit (4th grit).	
	Bowland shales.	300 to 800	Thin band of shales	100 to 120
	Pendle grit .	0 to 300	Absent . . .	
	Pendleside limestone . .	100 to 400	Absent . . .	
	Pendleside shales	about 1200	Absent or very thin	
Lower Carb.	Clitheroe and Cracoe limestones . .	over 3200	Yoredale beds . .	400 to 600
			Scar limestones . .	600 to 800

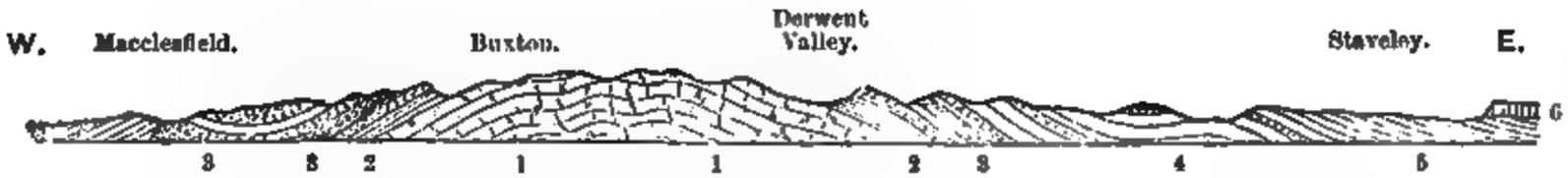

Fig. 73.—DIAGRAMMATIC SECTION ACROSS DERBYSHIRE. Distance about 35 miles.

6. Permian beds.
5. Middle Coal-measures.
4. Lower Coal-measures.
3. Millstone grits.
2. Pendleside shales.
1 Carboniferous limestone.

Fig. 74.—SECTION FROM BEN LOMOND TO THE PENTLAND HILLS. Distance about 45 miles.

4. Coal-measures.
3. Tuedian Limestone series
2. Oil-shale and sandstone group } Carboniferous rocks.
1. Red Sandstone group
v. Interbedded lava-flows

D. Lower Old Red Sandstone.
C. Silurian rocks.
B. Ordovician rocks.
A. Highland schists.
f.f. Faults.

The *Geological Survey Memoirs* give a much greater thickness in the Clitheroe and Pendle area than that above indicated, for they estimate the shales below the Pendleside limestone at 2500 feet, and make the Bowland shales range up to 1200 feet. Messrs. Hind and Howe, however, think that the only rocks which are truly referable to the Lower Carboniferous in that area are the massive limestones of Clitheroe and Cracoe, with a visible thickness of 3200 feet, and a possible thickness of 3500; but even this seems great when contrasted with the 1000 to 1400 feet of the Ingleton district.[6]

It has been thought that this great difference in thickness and composition could only be explained by supposing that the production of the Craven faults was contemporaneous with the deposition of the beds, repeated uplifts on the northern side keeping the water shallow, and so hindering the formation of thick limestones. But according to Messrs. Hind and Howe the change is mainly due to the very rapid thinning out of the beds which they call the Pendleside group. It should also be mentioned that they differ from the Geological Survey in considering that the Yoredale beds (a group of limestones, shales, and sandstones) replace part of the Clitheroe limestone, while the Survey regard them as equivalents of the Pendleside group.

The lower Clitheroe limestones are dark gray, but the upper beds are whitish and form irregular reef-like masses, the upper surfaces of which are uneven, and often rise into oval or conical eminences,[7] the depressions between them being filled by the shales of the Pendleside series, a conformation which may partly account for the variable thickness of these latter beds.

Passing now to the north of the Craven faults, the base of the Limestone series is well exposed near Ingleborough and Horton, the general succession being as follows:—

Gray limestones with *Chonetes papilionacea.*
Limestones with quartz pebbles and some fossils.
Brown sandstones and conglomerates with layers of black shale containing plants and *Leperditia Okeni.*
Green shales without fossils, resting on Ordovician.

These shales and arenaceous beds vary in thickness, but there are often 40 or 50 feet of them. The thick mass of gray limestone above was called the Scar limestone by Phillips.

The Yoredale beds consist of limestones with intercalated bands of shale and sandstone, the limestones being not lenticular but persistent bands, which have been traced for long distances, and each band has received a special name.

The highest of the Yoredale limestones is known as the "main

limestone," and the lowest as the "Hardraw limestone." Between these at Ingleborough there are three other limestones, and farther north two others come in, so that in Wensleydale there are seven Yoredale limestones (see table on p. 223). All these limestones, as well as those of the more massive series below, contain *Productus gigantea* and most of the fossils which occur in the Carboniferous limestone of Derbyshire and Lancashire.

Above the "main limestone" of Wensleydale there are some peculiar beds which, though of no great thickness (160 feet), are remarkable both in their lithological and palæontological characters. They include two beds of limestone, each of which is overlain by a band of chert beds; the lower set is known as the "Red Beds" and the upper as the "Crow limestone and chert." The chert in the Red Beds is 42 feet thick, and has yielded a remarkable set of fish teeth, an account of which, with a complete enumeration of the beds at Leyburn in Wensleydale, has been published by Mr. J. W. Davis.[8]

When followed northward the whole series becomes thicker. The basement beds pass into a thick group of red conglomerates and sandstones, which in the Cross Fell district are from 1000 to 1200 feet thick. Mr. Goodchild describes the succession illustrated by Fig. 75 as follows:[9]—

	Feet.
Limestone with a few thin bands of shale and sandstone . .	1000
Soft red sandstones with some pebbly beds, and including some layers of shale and of sandy limestone	500
Limestones without any intercalations	500
Gray shales passing down into green quartz conglomerates. .	200
Red conglomerates and sandstones with rock-fragments derived from the older rocks (? Old Red Sandstone) up to . . .	200

Towards Alston the main mass of limestone is still further split up by the intercalation of sandstones and shales, and expands to a thickness of 1600 feet, with twelve distinct beds of limestone. It begins in fact to assume the same facies as the Yoredale group which overlies it; the total thickness of the whole series near Alston is probably 3500 feet.

4. *Northumberland and Berwick*

The Lower Carboniferous series of these counties is a continuation of that just described, but not only does it occupy a still greater breadth of country, extending from Annan and Langholm in Dumfries across Northumberland to Morpeth and Alnwick, and from the Durham border to the Tweed, but the lithological composition of the series undergoes a still further change.

The basement beds, which had thickened to over 1000 feet in Cumberland, exhibit further expansion, and when they emerge on the Scottish border they are about 2000 feet thick, forming the lower part of a great arenaceous series, to which the name of *Tuedian* was given in 1856 by the late G. Tate, from its fine development on the valley of the river Tweed.

The limestone group completely loses its calcareous facies, and passes into a varied group of beds similar to the Yorkshire Yoredales. To this facies Mr. Lebour has given the name *Bernician*, from *Bernicia*, the Roman name of Northumberland.[10]

In the following table the Lower Carboniferous rocks of this region are grouped under these two heads, but the subdivisions and details are taken from the writings of Messrs. Hugh Miller and W. Gunn, of the Geological Survey.[11]

	Divisions.	Thickness in feet.
Bernician series.	*f. Fell-top division* (between the Millstone grit and the zone of the Great limestone). Sandstones and shales with some coals and one or more beds of marine limestone	350-1200
	e. Calcareous division (from Great limestone to base of Dun or Redesdale limestone). Sandstones and shales with coals and many beds of marine limestone . . .	1300-2500
	d. Carbonaceous division (Scremerston beds). Strata prevalently carbonaceous; limestones chiefly thin, many of them containing carbonaceous matter; coals . .	800-2500
Tuedian series.	*c.* Upper Tuedian or Fell sandstone group (Tweedmouth, Simonside, Harbottle, and Bewcastle Fells): a belt of massive grits with green, gray, and reddish shales; coals rare and thin	500-1600
	b. Lower Tuedian or Cement-stone group: sandstones and shales with bands of cement-stone passing into limestones near Rothbury and Bewcastle . . .	500-1500
	a. Basement conglomerates (Upper Old Red Sandstone)	0- 500

Tuedian Series.—*a.* The basement conglomerates occur locally round the Cheviot Hills, and are by some referred to the Upper Old Red Sandstone, but they pass up into the overlying sandstones, and certainly form a local base of the Carboniferous system. They are of a reddish brown colour and contain rolled pebbles of the Cheviot porphyrites.

b. These beds, generally called the Lower Tuedian, consist of yellow and reddish sandstones, gray and purple shales, greenish sandy clays (sometimes full of hard siliceous concretions), and beds

of hard cream-coloured earthy limestone or cement-stone in the upper part. In this group fossils are very rare and badly preserved, but *Modiola Macadami* occurs.

c. The lowest member of the Fell sandstone group is known as Harbottle grit, and in this the fossil *Archanodon Jukesi* has been found, a species which connects it with the Upper Old Red Sandstone of Ireland and the lowest Carboniferous beds in Scotland. The Harbottle grits and the other massive sandstones of this group form a broad belt of high and rugged country in the western part of Northumberland, rising into craggy hills and fells, such as those of the Chillingham and Simonside Hills and the Peel and Bewcastle Fells. The sandstones are divided by bands of shale, and a few thin seams of coal occur; plant remains are not rare, and the occurrence of *Lepidodendron veltheimianum* is notable. At or near the top of this group is a thin limestone with marine fossils of the usual limestone type.

Bernician Series.—On the southern border of Northumberland the massive Scar limestone of Yorkshire and the Yoredale beds are still distinguishable as separate stages, but as they are followed northwards they lose their distinctive character and merge into one great series of alternating limestones, shales, and sandstones with many workable beds of coal. The lower part of this Bernician series represents part of the Limestone group, and the central part appears to correspond with the Yoredale group, but there does not appear to be any well-marked or persistent bed which would serve as a line of division between them. Beds of this type stretch northwards from Hexham and Haltwhistle to the borders of the Cheviots, and north-eastward to the sea, forming the coast-line from Alnmouth to Berwick-on-Tweed.

The most remarkable feature in the Northumberland series is the great development of the mechanical sediments in the centre of the county. Some of the lower beds expand into the "Carbonaceous group" of Tate and Miller, while another series of sandstones and shales with coals and thin limestones come in above the main Yoredale limestone, forming the Felltop division. Thus, at Alston, between the "Felltop" and "Little" limestones, there is about 350 feet of shales and sandstones; in the Inghoe district, north of the Tyne, this interval has increased to 1450 feet, with three intercalated beds of limestone. Here the total thickness of the Bernician group is estimated at 6000 feet, but eastward it again diminishes, and along the coast it is once more reduced to between 2500 and 3000 feet.

Beds of coal occur throughout this Bernician series, but are thin and of poor quality in the central part, and are thickest and

most largely worked in the highest part (Felltop division). Professor Lebour remarks that the coal-seams are by no means so regular as those of the coal-measures above, being more liable to split up into two or three seams, and sometimes thining out altogether for a space. The seams generally rest on underclays full of stigmarian roots, but occasionally they lie directly upon shale or sandstone.

The limestones are thin as compared with those of Yorkshire, seldom attaining 20 feet, though one (the Great limestone) reaches to 40 feet in some places. They contain the usual corals, crinoids, and brachiopods, including *Productus giganteus* and *P. semireticulatus*. Parts of the "Eight-yard limestone" near Alnwick are largely made up of the large foraminifer *Saccamina Carteri*. Associated with some of the limestones, and in places representing them, are calcareous shales which are often rich in fossils, as in the case of the Redesdale ironstone shale near Hexham.

In consequence of the extensive mining for lead and coal, each bed of limestone has become familiar to the miners, who have given a special name to each; but these names are different in the different parts of the county, though it has recently been ascertained by the Geological Survey that many of the limestones are persistent from the southern to the northern border.

Mr. W. Gunn has recently published a correlation of the Lower Carboniferous series of Yorkshire, Northumberland, and Scotland, which is based on the researches of himself and the late Hugh Miller.[12] He states that the four Upper Yoredale limestones have now been traced all across the county, the "main limestone" of Yorkshire being the "Great limestone" of Teesdale, the "Ten-yard limestone" farther north, and the "Dryburn limestone" of Lowick. If this correlation is correct it follows that the whole Upper Bernician or Felltop division is above the real Yoredale group of Wensleydale, and is represented only by about 100 feet of cherty limestone and sandstone in Yorkshire.

The following table shows the successive limestones of the Yoredale, Alston, and Northumberland section, and I have followed Mr. Gunn's correlation except in respect to the Oxford limestone, which I have preferred to regard as the equivalent of the Simonstone instead of the Hardraw.

Scotland.	North of Northumberland.	Alston Moor.	Wensleydale.
Upper limestones and coals.	Measures with four thin limestones	Felltop limestone Crag limestone Little limestone	Cherty limestone
Edge coal group	Lickar coals	Shales limestone	

Scotland.	North of Northumberland.	Alston Moor.	Wensleydale.	
Lower limestone group	Dryburn limestone	Great limestone	Main limestone	Yoredale group.
	Low Dean limestone	Four-fathom limestone	Underset limestone	
	Acre limestone	Three-yard limestone	Little limestone	
	Eelwell limestone	Five-yard limestone	Fossil limestone	
Oil shale group	Five thin bands of limestone	Scar limestone, Cockleshell limestone, Singlepost limestone	Middle limestone	
	Oxford limestone	Tynebottom limestone	Simonstone limestone	
	Thin limestone above oil shale	Jew limestone	Hardraw limestone	
	Woodend limestone	Massive limestones	Massive limestones: Scar limestone.	
	Dun limestone			
	Scremerston beds	Limestones and sandstones		
	Thin limestone			

It is somewhat uncertain whether the Fell Sandstones (Upper Tuedian) represent any part of the Carboniferous Limestone, for they have not yielded any of its characteristic fossils. The Scremerston Beds, on the contrary, have yielded *Productus cora* and *P. giganteus* at several horizons, and the usual limestone fossils are plentiful in the Redesdale limestone of South Northumberland, which is the equivalent of the Dun limestone of the north.

5. *Scotland*

The central lowlands of Scotland display an enormous thickness of Lower Carboniferous rocks, which may be regarded as the expanded equivalents of the Tuedian and Bernician series of Northumberland, for the Scottish series is similarly divisible into a lower group, which is mainly arenaceous, and an upper more varied group of shales, sandstones, limestones, and coals. The lower has been called the Calciferous Sandstone series, and the upper was termed the Carboniferous Limestone series; but, as indicated above, the equivalents of the main mass of the Carboniferous limestone lie entirely below this "limestone series" of Scotland. Thus the nomenclature hitherto used by the Geological Survey and adopted in most text-books gives rise to misconception, and tends to exaggerate the stratigraphical importance of the upper part of the series. For while the upper portion, which has a thickness of only from 1600 to 1800 feet, has been

divided into three groups, the lower portion, which is over 6000 feet thick, exclusive of the Red Sandstone group, was undivided.

There is no question of the desirability of retaining the subdivisions of the upper series, but, as I am informed by Mr. Goodchild, the lower series is equally capable of subdivision into three groups, as shown in the following scheme, which is slightly modified from the tabular view given in his *Outline of the Geological History of the Rocks around Edinburgh*.[18]

Old Classification.	New Classification.	Thickness.
Upper limestone group	6. Upper limestone group . .	400 to 600
Edge coal group	5. Edge coal group . . .	600 to 800
Lower limestone group	4. Lower limestone group . .	500 to 600
Cement-stone group	3. Oil shale group	up to 3700
	2. Granton and Hailes sandstones .	,, 3400
	1. Ballagan beds	,, 1200
Red sandstone group	*b*. Cornstone beds	,, 1200
	a. Red sandstone and conglomerate	

The Red Sandstone Group has been described under the head of Old Red Sandstone (see p. 194), although it certainly passes up into the Carboniferous series, and is by some regarded as the base of that series.

The Ballagan Beds.—This name was first given to the beds which overlie the red sandstones near Glasgow, and may conveniently be employed to denote the lowest group of beds, which is undoubtedly Carboniferous, and is the equivalent of the Cement-stone group of Berwick.

It consists in the lower part of clays, shales, sandstones, and tuffs with some beds of dull compact limestone (cement-stone) and of siliceous sinter ; this part is about 200 feet thick. Next in the Edinburgh district comes the volcanic episode of Arthur's Seat, a set of basaltic lavas and tuffs with interstratified sandstones and shales, having a total thickness of 750 feet. These are covered by the Abbey Hill shales, which are 300 feet thick and contain marine fossils.

Granton and Hailes Sandstones.—This group consists of two thick sandstones separated by a band of shales. The lower member is the Granton Sandstone, probably about 800 feet thick ; the central band consists of the Wardie shales (400 feet), and the upper is the Hailes Sandstone, which may be 1000 feet thick. These sandstones form good building stones, and appear to correspond with the Fell Sandstones of Northumberland. In Fifeshire these are the lowest beds exposed in the coast section near Burntisland ; they have yielded few fossils, but the Wardie shales contain *Schizodus pentlandicus*, *Naiadites obesa*, *Anthracomya lævis*, and others.

Oil Shale Group.—This group is most fully developed in Fife, where its base is well marked by a bed of dark-coloured limestone known as the Burdiehouse limestone. This is an entomostracan limestone crowded with the cases of a small ostracod (*Leperditia Okeni*, var. *burdigalensis*). The group takes its name from the prevalence of black bituminous shales which contain large quantities of petroleum, some bands of them being so rich as to yield from 30 to 40 gallons of oil per ton of shale, besides a considerable quantity of sulphate of ammonia as a by-product in the process of abstraction.

The Oil Shale group consists mainly of shales and sandstones which contain the remains of fish, plants, and estuarine molluscs, especially *Naiadites obesa;* but there are many beds of limestone containing marine shells, and these sediments are interstratified with sheets of volcanic material, basalts, and basaltic tuffs, and are pierced by a large number of pipes and bosses of volcanic agglomerate which are the orifices of small volcanic vents.

The marine beds in this group have been carefully studied and described by Mr. J. W. Kirkby,[14] who found no fewer than eighteen limestones containing marine fossils. Four of these occur in the upper 500 feet, and the rest in the lower 1500 feet, the total thickness being put at 3800 feet. The fauna of the lower beds is characterised by the rarity of brachiopods and the abundance of lamellibranchs and gastropods. Of these the commonest are *Myalina crassa*, *Schizodus pentlandicus* (= *S. Salteri*), *Leptodomus costellatus*, *Macrocheilus acutus*, *Murchisonia striatula*, *Bellerophon Urei*, and *B. decussatus*, and many remains of fishes. In the upper 500 feet are *Productus cora*, *P. semireticulatus*, *Sanguinolites abdensis*, *Actinopteria persulcata*, and many other species.

Lower Limestone Group.—Near Edinburgh this group has a thickness of 400 feet to 500 feet, and contains three beds of limestones, but these are seldom more than 12 feet thick, though occasionally swelling out to 30 feet, and in the Bathgate Hills (Linlithgow) to 70 or 80 feet. In Ayrshire the Hurlet, or Main limestone, attains a thickness of 100 feet. *Spirifer trigonalis*, *Productus giganteus*, and *P. semireticulatus* are common fossils, and in some places the limestones are largely crinoidal, *i.e.* composed of the shelly plates which form the arms and stems of crinoids. These limestones are interbedded with a series of shales, sandstones, and coal-seams, several of the coals being immediately succeeded by a limestone, *e.g.* the Hurlet coal and limestone, as if there had been times when the shallow lagoons and swamps were suddenly submerged and occupied by marine organisms.

Edge Coal Group.—This is a shale and sandstone series, and

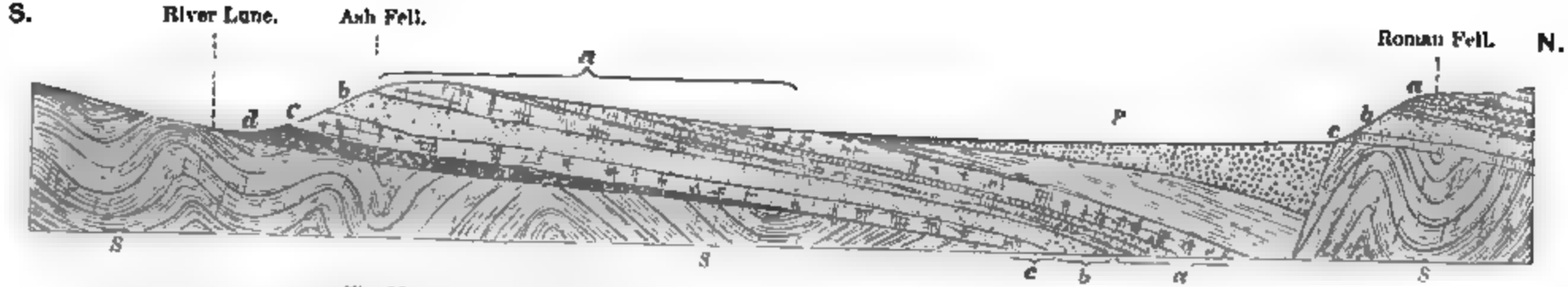

Fig 75.—DIAGRAMMATIC SECTION FROM HOWGILL FELLS TO ROMAN FELL (J. G. Goodchild).

a. Carboniferous limestone
b. Red sandstones
c. Shales and sandy limestones } Lower Carboniferous.

d. Upper Old Red Sandstone.
P Permian sandstone.
S Silurian rocks.

Fig. 76.—DIAGRAMMATIC SECTION THROUGH PART OF RENFREWSHIRE (after Sir A. Geikie).

6. The limestone group.
5. Oil shale group.
4. Andesites (volcanic group).
3. Volcanic tuffs.
2. Ballagan Beds.
1. Red Sandstone group.

it includes some valuable seams of coal, ironstone, and oil shale, but no limestones. In Midlothian its thickness is about 800 feet. Some of the beds contain marine shells, others are full of terrestrial plants, showing that the gradual submergence which was in progress was now and then counterbalanced by the deposition of the sediment brought down in such quantity by rivers.

Upper Limestone Group.—This is about 600 feet in Midlothian; it contains three bands of limestone and four seams of coal, interstratified with sandstone, shale, and fireclay. The limestones contain the same fossils as those of the lower group, and though seldom more than three or four feet thick, have been traced over an area of at least 1000 square miles, thus proving that the physical conditions of the period were very uniform over a large area.

In the western part of the Scottish lowlands near Glasgow the succession is similar, but with certain differences; the sandstones are very much thinner, and the greater part of the oil shale group is replaced by a thick mass of volcanic rocks. I am informed by Mr. Goodchild that the western succession may be tabulated as follows:—

		Feet.
Upper limestone group from the Castlecary to the Index limestone		150
Edge coal group with coals and ironstones		200
Lower limestone group (Hosie and Hurlet ironstones)		60
The volcanic series (chiefly lava-flows)		1000 to 2000
Gray and white sandstones		100
Ballagan beds, clays and shales with nodules and bands of argillaceous limestone		1200 to 1500
Reddish shales, clays, and cornstones Red sandstones	Upper Old Red	1500

A similar succession is found in the Isle of Arran, where, however, it would seem that the Ballagan shales are thinner and the overlying sandstones are thicker, with intercalated lava-flows. The volcanic group forms a nearly continuous band from Arran through Dumbarton and the Campsie Fells to the hills near Stirling, and it recurs in Ayrshire and the south of Renfrew. The Lower Limestone group which succeeds is, in Arran, of a red colour, and was formerly thought to be part of the Upper Old Red Sandstone, but the error of this view was pointed out by Mr. J. Nelson in 1896,[15] and has since been admitted by the Geological Survey. The red limestone of Corrie is now regarded as the local equivalent of the Hurlet limestone, and, like it, is characterised by the profusion of *Productus giganteus*. Both the Edge coal and the

upper limestones are found in Arran, and the latter are also stained red. The Index limestone is characterised by the abundance of *Productus latissimus.*

6. *Ireland*

In no country can the rocks of the Carboniferous system be better studied than in Ireland. They occupy fully one-half of the superficial area of the country, the whole of the great central plain, which stretches completely across the island from east to west, consisting of the Carboniferous limestone, though its surface is often covered by Pleistocene gravels. The lower groups of the system emerge from beneath the limestone to the north and south, while here and there the limestone plain supports hills of low elevation composed of the Coal-measures ; these outliers are the sole remnants of the beds which once spread over the limestone, and their survival is due to the circumstance of their lying in synclinal troughs or basins.[16]

For the sake of clearness and brevity the chief facts regarding the Lower Carboniferous series of Ireland will be given under three heads, (1) Antrim and Derry, (2) The Great Central Plain, (3) Cork and Kerry, the first and third of these areas each exhibiting a special and peculiar facies of the formation differing greatly from that of the central area.

Antrim and Derry.—Just as the Scotch Cambrian and Silurian rocks strike south-westerly into the north of Ireland, so also do the Scotch Carboniferous rocks. A series similar to that of Ayrshire is found near Ballycastle, in Antrim, and consists of the following groups according to Professor Hull :—

		Feet.
Edge coal series	Reddish and gray sandstones with seams of coal and black-band ironstone . . .	240
Lower limestone	Calcareous shales with two beds of compact argillaceous limestone	55
Cement-stone group	Red and yellow sandstones with beds of shale and a quartzose conglomerate at the base, resting upon mica-schist	1000

The diminished thickness of the Limestone series is remarkable, and yet the fossils leave little doubt of the correlation, for they include *Productus giganteus*, *Bellerophon Urei*, and *Orthoceras Steinhaueri.*

A similar series of beds is found in Derry, extending along the western border of the basaltic plateau, from the shores of Lough Foyle southward to Maghera and Drapersdown. At the base are thick reddish-brown conglomerates and sandstones, succeeded by

a great thickness of calciferous sandstone with bands of shale, which are well exposed in the valley of the Moyola River near Drapersdown. In these higher beds the commonest fossils are, *Leperditia Okeni*, *Modiola Macadami*, and *Protoschizodus axiniformis*, with *Dithyrocaris Colei*, *Cypris burdigalensis*, and remains of fish.[17]

Mr. Nolan compares the lower division with the Lower Calciferous sandstone of Scotland, and estimates its thickness at 1500 feet; the thickness of the upper division is uncertain owing to faults, but it is probably over 1000 feet.

Above these beds, at Cullion and Desertmartin, limestones come in which are arenaceous in the lower beds and dolomitic in the higher; the prevalent fossils are corals (*Lithostrotion junceum*, *L. affinis*) and brachiopods (*Productus giganteus* and *Orthis resupinata*).

Great Central Plain —The central part of Ireland, from the shores of Dublin and Meath to Galway Bay and Lough Corrib, is a great tract of low undulating land which seldom rises to more than 300 feet above the sea. In consequence of this low elevation, the general horizontality of the limestones below it, and the prevalence of Pleistocene deposits, exposures are few in the central area, and it is only in the outer parts, where the beds rise into hills, that the complete succession can be studied; the best sections are found on its northern, western, and southern borders.

On the northern border, in Tyrone, Fermanagh, and Leitrim, the general succession, according to Messrs. Hull and Hardman, is as follows :—

	Feet.
Gray limestones with nodules of chert	500
Carbonaceous shales and sandstones (Calp) . . .	1000
Lower limestones, gray and dark blue	600
Yellow sandstones and gray shales	200
Brown sandstones and conglomerates	500
	2800

The basal beds are sometimes called Upper Old Red Sandstone, but they rest unconformably upon the Fintona beds (see p. 196), and are now generally regarded as Lower Carboniferous because they seem to be the equivalents of similar beds in Derry and of the Red Sandstone group in Scotland. They consist of reddish brown conglomerates containing pebbles of white and pink quartz, succeeded by purple brown and gray sandstones and sandy shales, and above these are yellow sandstones and shales; no fossils have yet been recorded.

The lower limestones have shales at the base, and there is a gradual passage from these to limestones with beds of shale. The succeeding beds, known as the Calp, consist of massive light-coloured

sandstones with bands of shale and beds of impure coal; thin beds of earthy limestone also occur. The upper limestones contain *Productus giganteus* and other fossils, and are overlain by black shales which yield the same fossils as occur in the Pendleside group in England.

Westward, in Sligo and Mayo, there is a similar succession, but the basal beds are absent and the lower limestones pass laterally into beds of calcareous breccia and conglomerate, indicating a shore-line. The upper limestone rises into hills with bold craggy escarpments, while the softer beds of the calp have been eroded into broad vales.

As the series above described is traced southward through Mayo and Roscommon into Galway they exhibit a change similar to that which takes place in England, namely, a thinning of the sandstones and shales and a thickening of the limestones, till the series passes into a great limestone formation nearly 3000 feet thick, with the same black shales above and a still thicker set of basal sandstones. The following is the succession in Galway and Clare according to Mr. Kinahan:—

		Feet.
Burren limestone with layers of chert		1500
Middle limestone	Black limestone and chert Cherty zone	400
Lower limestone	The Fenestella limestone	300
	Lower cherty zone	100
	Shaly limestone	400
	Lower limestone shale	150
Basal beds or Old Red Sandstone		1000
		3850

The characteristic fossils of the Lower Limestone are *Fenestella flabellata*, *Michelinia favosa*, *Rhynchonella pleurodon*, *R. pugnus*, *Spirifer striatus*, *Cardiomorpha oblonga*, *Conocardium hibernicum*, and many cephalopods. Beds of the calp type occur toward the east at Loughrea and Portumna, and seem to be replaced in the west by the lower part of the upper or Burren limestone.

In the hills of Burren, County Clare, the upper part of the limestone is magnificently developed, and is thus described by Mr. Jukes[18]:—

"A range of hills, rather more than 1000 feet in height, sweep for about 20 miles along the south side of Galway Bay. They are formed entirely of bare rock from the sea-level to the hill-tops, the only soil being found in crevices of the rock, or in patches in the hollows of the valleys. This rock is all limestone, in regular beds, which dip gently to the south, at an angle of $1\frac{1}{2}$

degrees only, and counting from the lowest bed that rises out on the sea-shore to the uppermost, which caps the summit of the hills three or four miles to the southward, there must be a thickness of at least 1600 to 1700 feet of solid limestone shown here.

Still farther south, in Limerick and Tipperary, there is a similar succession, but the basal sandstones and conglomerates have increased to a thickness of 2000 feet, and the Limestone series above attains a thickness of about 3500 feet, its thickest member being the Fenestella limestone (1500 to 1900 feet), while the upper (Burren) limestone has decreased to only 240 feet. The same succession of limestones can be followed eastward through Kilkenny and Carlow, but the basal beds become thinner in this direction. Fig. 88, across the Castlecomer coal-field, illustrates this part of the area.

The lower conglomerates appear to die out in Kilkenny, but the yellow and greenish sandstones still range through that county, and at Kiltorcan, near Thomastown, they have yielded the assemblage of fossils mentioned on p. 197, and seem to be of freshwater origin. Still farther east these beds are overlapped by the limestones, which then rest directly on the granite of Carlow, and a little to the northward, in County Dublin, shales of the calp facies overlap the limestones, thus giving evidence of another shore-line.

Southern Counties.—When the Carboniferous rocks are traced to the south-west through Cork and Kerry a still greater and much more sudden change takes place in the constitution of the system. This consists in the introduction of what appears to be a distinct group of shales and slates between the Yellow Sandstone and the Carboniferous Limestone, and to which Sir R. Griffith gave the name of *Carboniferous Slate.* This group of beds has derived special importance from its bearing on the Devonian question, and the whole subject is so associated with the name of Jukes, that it would be idle to attempt a better exposition of the interest attaching to the Carboniferous Slate than is contained in Mr. Jukes's own description quoted below.[19]

"If we draw a parallel of latitude through the towns of Kenmare, Macroom, and Cork, the great development of Carboniferous Slate lies wholly south of that line. If we examine the neighbourhood of the city of Cork itself, we find the [Upper] Old Red Sandstone with plants in its upper beds, and a very short distance above that we get solid Carboniferous limestone, with some black shales or slates between the two, but not more than 200 or 300 feet in thickness. Passing southwards to the mouth of the harbour of Monkstown or Queenstown, and then by Carrigaline

and Coolmore, these intermediate black slates or shales thicken to 2000 or 3000 feet, still having the Old Red below and the Carboniferous Limestone above; but going still farther south by Ringabella to Kinsale, the dark gray slates and gray grits thicken rapidly to 5000 or 6000 feet, and are nowhere covered by any part of the Carboniferous Limestone, though they show here and there highly calcareous bands.

"The whole of the rocks are thrown into numerous anticlinal and synclinal curves, over many interrupted axes, which strike very steadily from E.N.E. to W.S.W.; and the headlands and bays along the south coast of Cork exhibit numerous transverse sections across the beds, so that no mistake can be made respecting the facts."

Fig. 77 is a copy of the section drawn by Mr. Jukes to

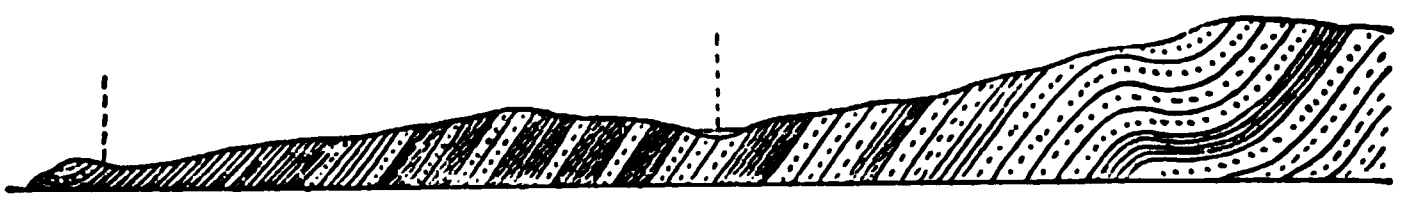

Fig. 77.—SECTION NEAR GLENGARIFF (JUKES). Distance about 2½ miles.

		Feet.
Carboniferous Slate	*e.* Black slates with calcareous bands *d.* Black and gray slates	2000
	c. Coomhola grits, greenish gray grits with black and gray slates; marine fossils	3000
Glengariff Grits	*b.* Greenish gray grits with green and purple slates and occasional cornstones	5000
	a. Glengariff grits, massive green and purple grits, with thin bands of purple slate	

illustrate the relative position of the beds on the east side of Glengariff Harbour at the head of Bantry Bay, where the grits in the Carboniferous Slate have a conspicuous development and are well seen in the banks of the Coomhola River, whence they have been called the Coomhola Grits. Here, as Mr. Jukes observes, the boundary between the two sets of grits can only be determined by noting the change in the colour of the slate bands which are interbedded with them.

Now the question naturally arises, What part of the Carboniferous series do these slates and grits represent? Although they appear to fit in wedgewise between the Yellow Sandstone and the Carboniferous Limestone, yet the probability is that they correspond to much more than the Lower Limestone Shale. At Whiddy Island, at the head of Bantry Bay, there are black shales containing *Posidonomya Becheri* and *P. membranacea*, the characteristic species of the shales above the limestone, and it is therefore

highly probable that the Carboniferous slate is contemporaneous with the whole of the Carboniferous limestone, the lower and upper parts of that formation passing laterally into shales, just as its middle part does to the northward. We may therefore regard the Carboniferous slate as representing the whole of this limestone and its underlying shale, *i.e.* strata amounting to a thickness of 2600 feet in the northern part of Ireland; such in fact was Mr. Jukes's opinion.

There remains, however, the question of the Coomhola Beds. Are they truly part of the Carboniferous series, and do they graduate downward into the Glengariff Grits, or is there an unconformity between the two? Jukes could find no evidence of unconformity, and thought the sequence was continuous and unbroken; but there is such a great break between the two systems in the Dingle promontory to the north, where the Glengariff grits are overlain unconformably by a great thickness of red conglomerates and sandstones, that one is naturally led to suspect the reality of the apparent conformity near Kenmare and Glengariff.

Professor Hull went over the whole district in 1878-80, and his view is that the conglomerates and sandstones thin out southward and allow the higher beds to rest directly on the Glengariff grits.[20] This has been explained more fully on p. 197.

With respect to the fossils of the Coomhola Beds, the majority of them are Carboniferous species, but there are a few which also occur in the Upper Devonian of North Devon, and show that these beds occupy a low horizon in the Carboniferous series. These species are marked with an asterisk in the following list, but the fauna of the Marwood and Pilton Beds, as recently described by Rev. G. F. Whidborne,[21] seems to differ considerably as a whole from that of the Coomhola Beds.

Lepidodendron veltheimianum.
Athyris ambigua.
*Lingula squamiformis.
*Rhynchonella pleurodon.
Spirifer cuspidatus.
,, striatus.
*Orthotetes crenistria.
Terebratula hastata.
*Avicula damnoniensis.
Modiola Macadami.
Aviculopecten arenosus.
*Cucullæa Hardingi.
*Curtonotus elegans.
Nuculana attenuata.
Sanguinolites plicatus.
*Bellerophon subglobatus.
Orthoceras undulatus.

The calcareous bands in the upper black slates of Reenydonagan yield *Phillipsia pustulata*, *Productus scabriculus*, *Rhynchonella pleurodon*, *Fenestella antiqua*, *Chætetes tumidus*, and other Carboniferous Limestone fossils.

Volcanic Rocks

England.—In Cornwall and Devon the lower part of the Carboniferous series contains sheets of lava and volcanic ash similar to those which occur in the underlying Devonian series. These have not yet been carefully examined, with the exception of those in the neighbourhood of the hill called Brent Tor, near Tavistock. This well-known hill appears to be a portion of a volcanic cone, though the actual crater and the greater part of the cone have been demolished by repeated detrition and erosion. The present hill is about 1100 feet high, and consists of masses of devitrified rhyolite and pitchstone, with some basalts and beds of volcanic breccia, the two first being evidently parts of ancient lava-flows.[22] In the country surrounding the Tor, beds of shaly volcanic ash are interbedded with the Culm-measures; these were probably ejected from the volcano of the Tor, which must have been either a submarine vent or a volcanic island.

In South Staffordshire the Coal-measures are penetrated by many intrusive dykes and sheets, some of which form considerable surface areas; these intrusions are considered by Mr. Jukes to have taken place during the deposition of the Upper Coal-measures, for he found ashy sandstones, *i.e.* sandstones partly formed of volcanic ejectamenta, at several horizons from 400 to 900 feet above the "thick coal"; moreover, the sheets and dykes are displaced by the faults that traverse the Coal-measures.

In North Staffordshire (Congleton Edge) a band of tuff and agglomerate is interbedded with the highest portion of the Carboniferous Limestone[23] (see Fig. 87, p. 260).

In Derbyshire several interbedded sheets of trap occur in the Carboniferous Limestone, and are locally known as *toadstones*, probably from their spotted appearance. They consist of dolerite, which is sometimes dark and compact, but more often greenish, earthy, and amygdaloidal; they average 50 or 60 feet in thickness, and have been traced for many miles; they are sometimes associated with beds of green and purple ash or tuff. These lavas appear to have flowed from more than one volcanic vent, as they sometimes thicken in opposite directions.

Beds of greenish tuff and coarse ash occur in the black limestone group of the Isle of Man, and the centre of eruption appears to have been at the Stack of Scarlet, where there are several volcanic vents filled with masses of agglomerate, one having a central plug of diabasic lava.

Scotland.—The lower part of the Carboniferous system in Scotland is full of such striking instances of volcanic activity that

it becomes an excellent district for the study of such phenomena. The most persistent zone of volcanic rocks is that which succeeds the Ballagan Beds; "great sheets of porphyrites, with interbedded tuffs, sandstones, and conglomerates, rise in broad masses, bed above bed, and form that conspicuous chain of terraced heights which stretches from near Stirling, through the range of the Campsie, Kilpatrick, and Renfrewshire hills, to the banks of the Irvine in Ayrshire, and thence westwards by the Cumbrae Islands and Bute to the south of Arran" (A. Geikie).

The Edinburgh district includes the volcanic centres of Arthur's Seat and Craiglockhart Hill.

In the succeeding phases of the Oil Shale and Limestone groups (see p. 230) volcanic outbursts occurred both in the western and eastern districts. Fife and the Lothians seem to have been dotted over with many small volcanoes, which, either singly or in groups, ejected lavas and ashes for a time and then became inactive, allowing other similar vents to form and take up the *rôle* of action, so that the district must at the time have presented an appearance like that of Auvergne; and now the Carboniferous rocks are intermingled with innumerable small sheets of basalt and tuff, and are pierced by intrusive dykes and necks filled with volcanic ash or basalt, but there are nowhere such extensive and massive sheets of lava as occur in the underlying and older groups.

Many of the vents from which these tuffs and lavas were ejected can still be indicated, and Sir A. Geikie has distinguished six different volcanic districts in the basin of the Forth, viz. (1) Haddington, (2) Edinburgh, (3) Linlithgow, (4) Stirling, (5) West Fife, (6) East Fife.

In the Haddington district many old vents occur, some filled with tuff and agglomerate, others with lava; the Bass Rock, North Berwick Law, and Traprain Law are instances. The oldest lavas are augitic (dolerites, etc.), the newer are variously coloured porphyrites; interstratified tuffs and agglomerates are frequent.

In Linlithgow there are many half-destroyed volcanic cones, and the Binns Hill is a neck or stump composed mainly of fine green tuff. In West Fife there are two groups of volcanic vents, one forming the Saline and Cleish Hills, the other near Burntisland. Largo Law is a very perfect example of a double cone, each composed of tuff with central pipes filled with basalt. Saline Hill has a similar structure, the whole mass resting on beds belonging to the Edge coal group, and the outer tuffs of the cone dovetailing into higher strata.

In Stirlingshire some interesting necks occur, those of the Fintry Hills having central hollows suggestive of the original craters.

Near Kilsyth the interstratified volcanic material is 1000 feet thick, but this thins away north-eastward, and disappears near Stirling in a distance of 13 miles.

It is, however, in the west of Scotland that the largest vent or connected group of vents is found; this lies among the uplands of Misty Law in the heart of Renfrewshire, "where a connected mass of tuff and agglomerate now occupies a space of about 4 miles in length by 2½ miles in breadth."[24] From this centre great sheets of andesitic lava extend in several directions for distances of 8 to 10 miles, and their maximum thickness round Misty Law is at least 1500 feet (see Fig. 76, p. 233).

Ireland.—County Limerick was the scene of powerful volcanic disturbances during the accumulation of the Carboniferous limestone, some enormous masses of felstone, tuff, and conglomerate being included in the limestone, ejected probably from submarine vents which may sometimes have formed temporary volcanic islands. An account of these rocks has been given in another[25] book, but it may here be mentioned that Professor Hull distinguishes two epochs of eruption in the Limerick area, the first witnessing the extrusion of felspathic lavas and ashes, while the second, which occurred after a considerable interval, gave birth to flows of basaltic lava.

B. The Upper Carboniferous Series

Subdivisions.—This great series may be divided into five groups or stages, which are given below in descending order, with their average thicknesses:—

	Feet.	
Upper Coal-measures	2000	Freshwater.
Middle Coal-measures	3000	
Lower Coal-measures	1000	Mainly marine.
Millstone Grit	1000	
Pendleside group	1000	

Of these the Millstone Grit is quite the most variable member, for while it is about 4000 feet thick in Lancashire it thins away northward, and becomes quite a subordinate member of the series in Northumberland and in Scotland, so much so, in fact, that it is difficult to say which beds are really the equivalent of the Millstone Grit. Moreover, the very name is misleading, for though in the south of England and Wales the group consists almost entirely of Sandstones, in the north it consists of several thick sandstones divided by thick masses of shale, and includes some coal-seams.

The whole series indeed is made up of repeated alternations of sandstones and shales, with occasional beds of coal, each band of

sandstone and shale varying greatly in thickness and forming a lenticular mass of greater or less extent. The sandstones are thickest and coarsest in the lowest stage, while shales and marls prevail in the higher Coal-measures.

The average thickness of the series where it is complete may be put at from 7000 to 8000 feet, but in some districts it swells out to 11,000 feet, while in the Midland counties the lower stages thin out, and the other stages successively overlap one another on to older rocks.

Just as the Lower Carboniferous series is in most places brought to the surface along tracts of anticlinal flexure, so the upper series is generally found in synclinal troughs or basins, the highest portion of the series usually lying in the central parts of such basins. All areas where workable coals exist are called *coal-fields*, and the following is a list of the productive coal-fields of Great Britain.

1. *Coal-fields of England and Wales*

1. South Wales (large).
2. Bristol and Somerset.
3. Forest of Dean (small).
4. Forest of Wyre (small).
5. Shrewsbury (small).
6. Coalbrook Dale.
7. Denbigh and Flint.
8. Anglesey (small).
9. South Staffordshire.
10. North Staffordshire (large).
11. Cheshire (or Park Gate), small.
12. South Lancashire and Burnley (large).
13. North Lancashire (small).
14. Cumberland (Whitehaven).
15. Durham and Northumberland (large).
16. Yorkshire, Derby, and Notts (large).
17. Leicestershire (small).
18. Warwickshire.

2. *Coal-fields of Scotland*

Six separate coal-fields may be distinguished in the great band of Carboniferous rocks which occupies the central lowlands of Scotland, but it must be remembered that in this country the best coal-seams occur in the Lower Carboniferous series. The equivalents of the upper series only occur in the three to which a star is affixed.

1. Lanark and the Clyde Basin*.
2. Midlothian *.
3. Ayrshire *.
4. Lesmahagow.
5. Fifeshire.
6. Clackmannan.

3. *Coal-fields of Ireland*

1. Munster coal-field (Clare, Limerick, and Cork).
2. Tipperary coal-field (small).
3. Leinster coal-field.
4. Leitrim (small).
5. Tyrone.
6. Antrim (Lower Carboniferous).

Some of the English coal-fields are only partially exposed, large portions of them being covered by newer rocks, so that the outer limits of some are not known. Others are almost certainly connected beneath these newer rocks: thus the Midland coal-fields are probably only the exposed portions of one large coal-field, including North Staffordshire, which again has doubtless a subterranean connection with that of Denbigh, while that of Flint is united to that of South Lancashire beneath the plains of Cheshire (see Fig. 43, p. 259). There are also some coal-fields which are entirely concealed, as that recently discovered below Kent and that of Witney in Oxfordshire.

Life of the Epoch

The fauna and flora of the Upper Carboniferous series are mainly of terrestrial and freshwater character, because the whole series was accumulated in close proximity to land; but during the formation of the Millstone Grit and Lower Coal-measures marine conditions were still prevalent, and consequently these groups include many beds in which marine fossils occur, but most of the species recur at successive horizons, and no zones have been established. Little has yet been done in Britain towards separating the floras of the successive stages, so that it is at present uncertain how far the different measures can be distinguished by their fossil plants. Mr. Kidston, however, has shown that the floras of the Lower, Middle, and Upper Coal-measures are distinguishable from one another, and in France a succession of plant-zones has been described by M. Grand' Eury.

1. *The Flora*

1. **Filices** (*Ferns*).—Fern-leaves abound in almost every coal-seam and its associated measures, the coal-roof being sometimes completely covered with the impressions of beautiful fronds. It is difficult to say how many of the fronds belonged to stemless ferns, or whether the majority are not the fallen leaves of arborescent ferns resembling the tree-ferns of the tropics. Stems of such tree-ferns have been found resembling some recent forms in the size and disposition of the scars left by the detachment of the frond stalks. Fronds bearing fructification are occasionally found, but most of the present genera are distinguished only by the nervation and form of the pinnules (or leaflets),—characters which are sufficient for the distinction of species, but are not trustworthy guides in the grouping of species into genera.

Among the genera which have been founded on the barren

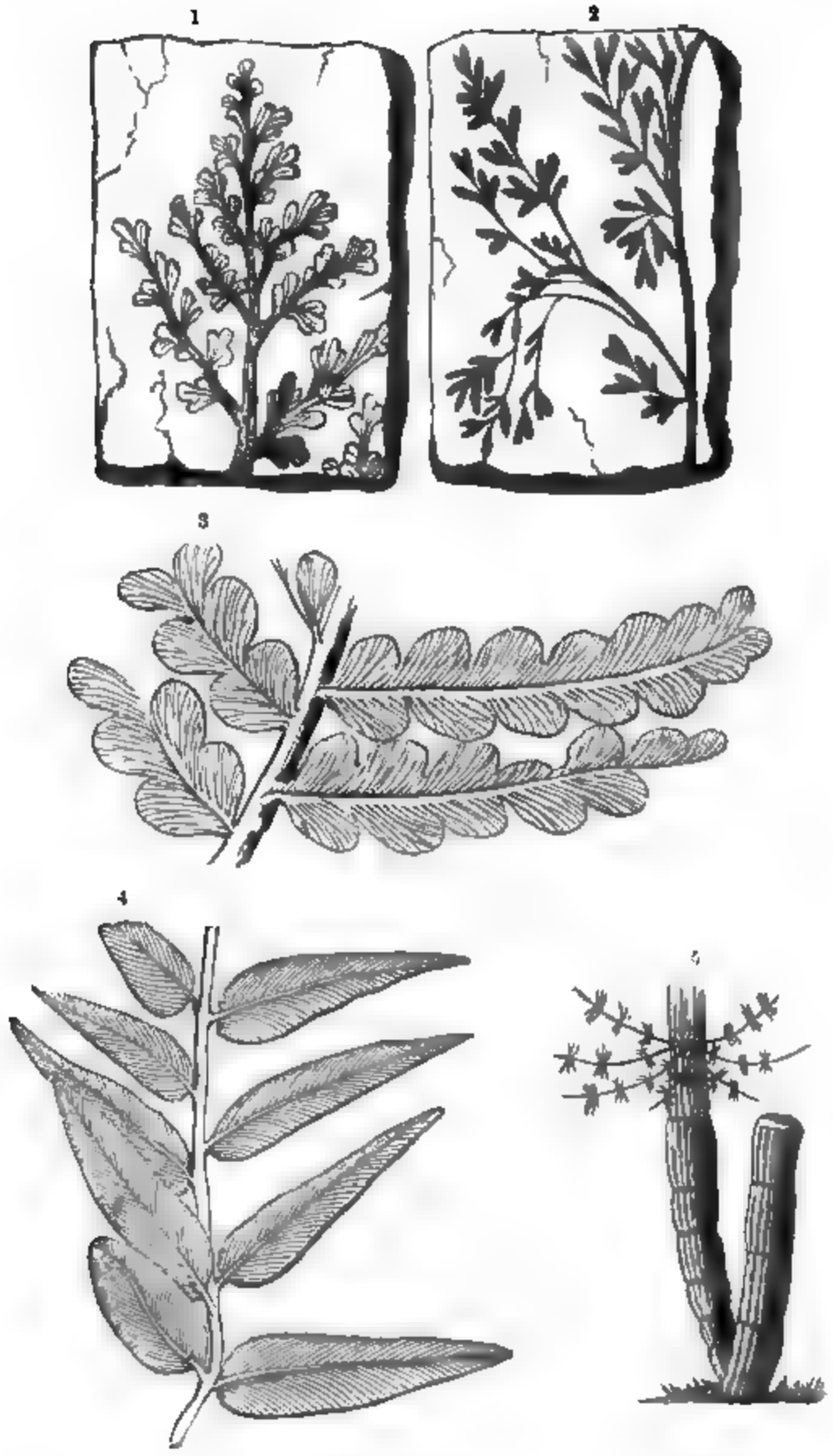

Fig. 78.—GROUP OF COAL-MEASURE PLANTS.

1. Sphenopteris linearis.
2. Sphenopteris affinis.
3. Odontopteris Schlotheimi.
4. Neuropteris acuminata.
5. Calamites (restored and $\frac{1}{20}$th of natural size).

fronds, the following are some of the most abundant: *Alethopteris* (Fig. 79, *b*), *Neuropteris* (Fig. 78), *Palæopteris*, *Pecopteris*, *Odontopteris* (Fig. 78), *Sphenopteris* (Fig. 78), *Sagenopteris*, *Cyclopteris*.

2. **Equisetaceæ.**—*Calamites* were gigantic Equiseta or horsetails, and consisted of a large central column of soft tissue encased in a cylinder of woody tissue. The central part has generally perished and disappeared, and the cavity thus left has been filled

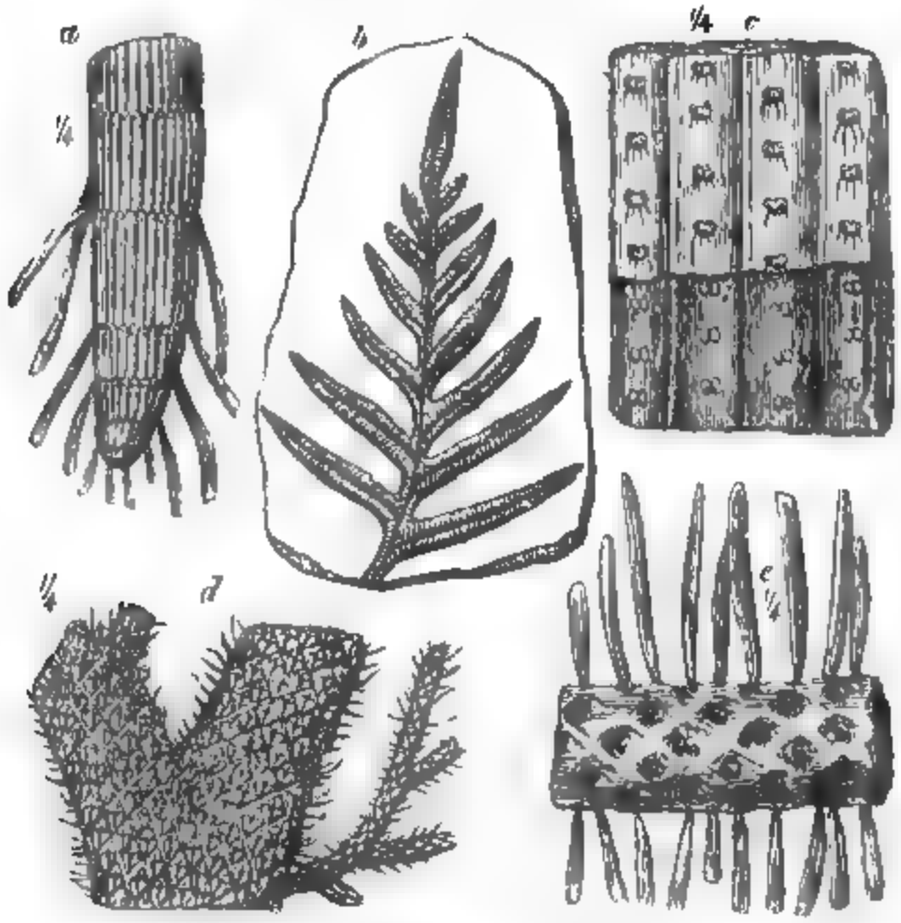

Fig. 79.—GROUP OF COAL-MEASURE PLANTS.

a Calamites cannæformis (root end). *c*. Sigillaria reniformis.
b. Alethopteris lonchitica. *d*. Lepidodendron Sternbergi.
e. Stigmaria ficoides.

up with mineral matter, forming the casts which are such common Carboniferous fossils. The outer ligneous envelope, being carbonised and friable, is seldom preserved in a perfect state.

The name *Calamites* is at present restricted to these jointed stems, while other names, *Asterophyllites*, *Annularia*, and *Sphenophyllum*, are given to different varieties of foliage, which are believed to belong to *Calamites*. The fruit is a scaly spike (*Volkmannia*), in which sporangia are arranged like those of Equisetum.

Calamodendra are casts of the central cavity or pith of plants resembling Calamites, but having a thick woody outer coating or bark. *Calamodendron* thus appears to have been a highly developed Equisetum, and may have been a connecting link between Acrogens and Gymnosperms.

3. Lycopodiaceæ.—*Lepidodendra* were gigantic members of

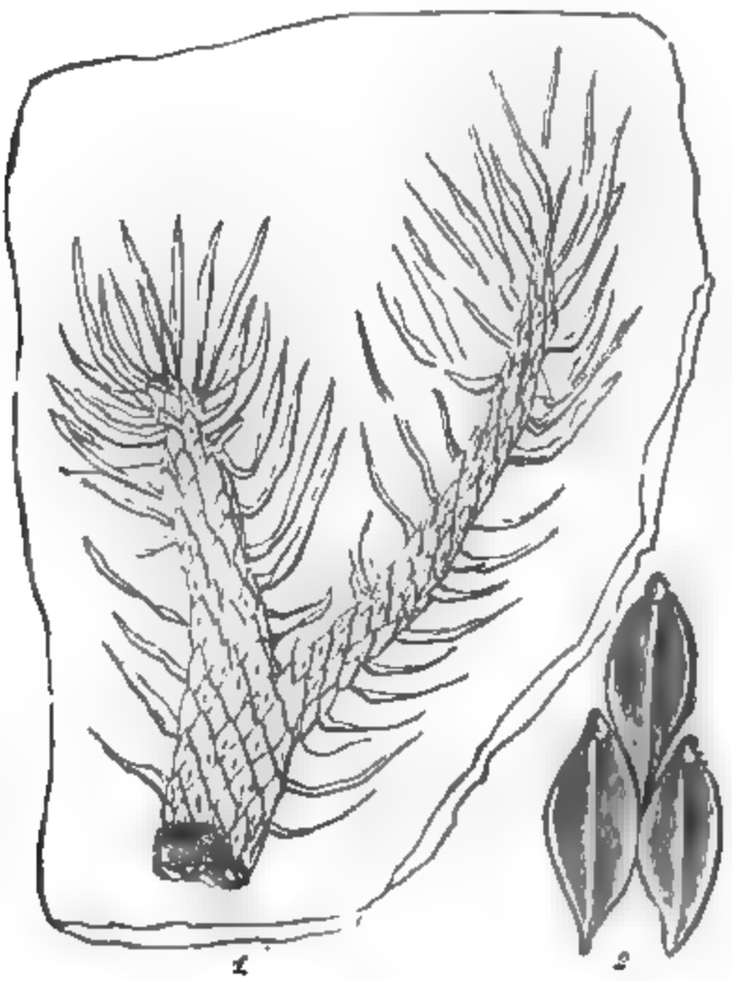

Fig. 80.—LEPIDODENDRON.

1. A terminal branch. 2. Leaf scars from the stem

the Lycopodiaceæ, or Club-moss family, having trunks many feet in girth, and 40 to 60 feet in height. The trunks branch toward the top into several limbs, which divide again into smaller boughs. The foliage consists of simple linear leaves, which are sometimes found attached to the terminal branches (Fig. 80), and the angular scars on the stem are the marks left by the detachment of these leaves. *Ulodendron*, *Knorria*, and *Halonia* are allied genera.

The scaly cylindrical bodies which are known as *Lepidostrobi* are

the cones which contain the sporangia or seed-cases of the Lepidodendra, and were borne at the extremities of some of the branches.

Sigillaria.—These appear to have been the commonest trees in the swampy portions of the Carboniferous forests, and have evidently supplied the chief mass of the material which forms our coal-seams, while their roots (*Stigmariæ*) ramify in the under-clays beneath. They were tall-trees, branching at the top, and rivalling the Lepidodendra in height, with a bare trunk fluted longitudinally, and regularly ornamented by the pits or scars left at the points where the leaf-stalks were attached. These leaves were long and narrow, and were first described under the name of *Cyperites*. The fruit consists of small sporangia borne at the basis of slightly modified leaves; *Sigillaria* was therefore a Lycopod, and allied to *Lepidodendron*. The roots (*Stigmariæ*) were long, branching, and tapering, with numerous radicles spreading out in all directions; such roots have been found which were upwards of 20 feet in length. Perhaps, like those of the modern mangrove-tree, these roots were partly aerial, rising well above the low-water mark of the swamp, and uniting in a dome-shaped manner to support the trunk.

4. Coniferæ.—The stems of true Coniferæ (*Pinites*, *Dadoxylon*, and *Araucarioxylon*) have also been met with, especially in the volcanic tuffs of the Scotch Carboniferous series. The lower slopes of the old volcanoes were doubtless clothed with these pine-trees, their habitat being in such high and dry localities, and not in the swampy ground where the other plants flourished. The fruits called *Trigonocarpon*, of which there are many forms abounding in the Coal-measures, are now supposed to have belonged to conifers of the yew tribe.

Cordaites was a remarkable plant placed by most botanists with the cycads, but by some with the conifers. The stem grew to a height of 20 or 30 feet, and carried a number of long sword-shaped leaves with parallel venation, something like those of a yucca. The leaves were attached by broad bases, and left large leaf-scars on the stem when they fell off. The tree bore bunches or spikes of fruit (*Antholites*), with berries somewhat resembling those of a yew, but more heart-shaped, and these are known as *Cardiocarpum*. Both leaves and fruit are very abundant in some of the Coal-measures.

M. Grand' Eury has divided the Upper Carboniferous series of Central France into six zones, which, however, seem to be characterised rather by the relative abundance of certain genera than by the limitation of species. The following is an abridgment of the characters given by him :—

1. *Infra Coal-measure Flora* (= Millstone Grit).—Characterised

by abundance of Lepidodendra and Stigmaria. Ferns abundant, *Sphenopteris* being the prevalent genus. *Calamites* not relatively abundant, and *Sigillaria* rare.

2. *Middle Coal-measures, Zone a.*—Sigillarias very numerous; Calamites also abundant, and Lepidodendra equally so. Of ferns *Sphenopteris* and *Neuropteris* are abundant with *Cyclopteris obliqua* and *Alethopteris lonchitica.*
3. *Middle Coal-measures, Zone b.*—Sigillarias more abundant than the Lepidodendroids, and showing a large number of species; Calamites are numerous, and Sphenophyllum especially so. Ferns more varied, *Sphenopteris* being associated with many other genera.
4. *Middle Coal-measures, Zone c.*—*Calamites* and their foliage very numerous, especially *Annularia* and *Asterophyllites. Sigillaria* and *Stigmaria* common. Ferns as in zone below. *Cordaites* begins to be numerous.
5. *Upper Coal-measures, Zone a.*—*Calamites* and their foliage still very abundant both in species and individuals. Lepidodendra few, but Sigillarias are not uncommon. *Sphenopteris* rare, but *Neuropteris, Odontopteris,* and *Pecopteris* are common. *Cordaites* reaches its maximum in point of abundance.
6. *Upper Coal-measures, Zone b.*—*Calamites* abundant. *Cordaites* still prevalent, and ferns are in great profusion, particularly species of *Pecopteris* (*P. Schlotheimi, unita, arguta,* etc.), *Odontopteris* (*xenopteroides* and *mixoneura*), *Caulopteris macrodiscus, Alethopteris Grandini,* and *Callipteridium ovatum, C. gigas,* etc. Conifers are represented by *Walchia piniformis.*

2. *The Land and Freshwater Fauna*

Mollusca.—In the Coal-measure shales, and associated with many of the plants above-mentioned, shells somewhat resembling the recent *Unio* are frequently found. They have been referred chiefly to three genera, *Carbonicola* (= *Anthracosia*), *Anthraconya,* and *Naiadites,* and their affinities have recently been studied by Dr. W. Hind, who refers the first two genera to the *Unionidæ* and the third to the *Mytilidæ,* but believes that all of them were freshwater forms. He remarks that their occasional or rare association with marine shells is no proof that they were capable of living in salt water, for their shells may have been carried down by rivers into bays and estuaries.

Arthropoda.—True Insects, Myriapods and Arachnids, have also been found in the Coal-measures, including crickets, beetles,

and a scorpion. Crustacea also inhabited the waters, the small Ostracoda—*Bairdia*, *Leperditia*, and *Beyrichia*, and the Phyllopod *Estheria*—swarming in some localities. Several species of Xiphosura allied to the modern *Limulus* (king-crab) have been described by Dr. H. Woodward, and referred to the genera *Prestwichia* and *Belinurus*. There were also a few Eurypterids, this being their last appearance in England.

Fishes.—Fish remains, of Crossopterygian and Elasmobranch genera, are everywhere abundant, but it is difficult to separate entirely the freshwater forms from the marine, because some (like the Mollusca) seem to have been equally at home in salt and brackish water; some of them, like the modern salmon, may have lived in the sea at certain seasons, and in the estuaries and rivers during other parts of the year. The following genera are, however, most frequently associated with the Coal-measure plants:—*Cœlacanthus*, *Cheirodus*, *Ctenacanthus*, *Ctenoptychius*, *Gyracanthus*, *Megalichthys*, *Platysomus*, *Pleuracanthus*, *Rhizodus*, *Rhizodopsis*, and *Strepsodus*.[a]

Amphibia.—Thirteen genera of Labyrinthodonts are recorded from British Carboniferous rocks, *Anthracosaurus*, *Loxomma*, *Ophiderpeton*, *Urocordylus*, etc., mostly from the Jarrow coal-field in Leinster, Ireland. Others (*Archegosaurus*) occur in Prussia and (*Baphetes*, *Dendrerpeton*) in Nova Scotia. Footprints have also been observed in the Forest of Dean coal-field and in the Limestone series of Dalkeith, Scotland. The larger of these Amphibians is believed to have measured seven or eight feet in length, but others were very small; they were probably fluviatile creatures preying on the fish and Crustacea which swarmed in the swamps and lagoons of the period.

3. *The Marine Fauna*

Although the Millstone Grit and the Lower Coal-measures appear to be mainly marine deposits, yet marine fossils only occur at certain horizons, and the fauna is not a large one. Some of the species which have been found in these stages and at two horizons in the Middle Coal-measures of Staffordshire are tabulated on p. 251, and the first column shows how many range up from the Lower Carboniferous series.

Local Stratigraphy

In dealing with the Upper Carboniferous series it will be

[a] Dr. Traquair considers that the genera *Palæoniscus*, *Amblypterus*, and *Pygopterus* are Permian forms only, and that the Carboniferous fish described under these names belong to other genera.

	From Carb. L.	Pendle Group	Millst. Grit.	Lower C.M.	Middle C.M.
Acanthodes Wardi, *Eg.*			×	×	
Elonichthys Aitkeni, *Traq.*			×		
Acrolepis Hopkinsi, *M'Coy*			×		
Goniatites (Gastrioceras) carbonarius, *v. Buch.*		×	×	×	
,, ,, Listeri, *Martin*		×	×	×	
,, (Glyphioceras) bilinguis, *Salter*		×	×	×	
,, ,, diadema, *Beyr.*		×	×		
,, ,, reticulatus, *Phil.*		×	×	×	
,, ,, spiralis, *Phil.*			×		
Cælonautilus falcatus, *Sow.*				×	×
Pleuronautilus quadratus, *Flem.*	×				×
Temnocheilus carbonarius, *Foord*					×
,, concavus, *Sow.*					×
Ephippioceras clitellarium, *Sow.*		×		×	×
Orthoceras Steinhaueri, *Phil.*	×	×	×	×	
Euomphalus tuberculatus, *Flem.*					×
Pleurotomaria monilifera, *Phil.*	×	×	×		
Macrocheilus michotianus, *de Kon.*					×
Bellerophon hiulcus, *Sow.*		×	×	×	×
,, Urei, *Flem.*	×	×	×	×	
Allorisma sulcata, *Flem.*	×	×			
Nucula sequalis, *Sow.*	×		×	×	×
,, gibbosa, *Flem.*	×	×	×	×	×
Nuculana stilla, *M'Coy*	×		×	×	
Ctenodonta sinuosa, *de Ryck.*	×	×	×		
Myalina Flemingi, *M'Coy*			×		
,, Verneuilli, *M'Coy*	×		×		
Protoschizodus orbicularis, *M'Coy*			×		
Schizodus antiquus, *Hind*		×	×		
,, carbonarius, *Sow.*				×	
Posidoniella lævis, *Brown*		×	×	×	
,, minor, *Brown*		×	×	×	
,, semisulcata, *Hind*		×	×	×	
Posidonomya Becheri, *Bronn*	×	×	×	×	
Actinopteria persulcatus, *M'Coy*	×	×	×		
Aviculopecten fibrillosus, *Salter*		×			×
,, papyraceus, *Goldf.*		×	×	×	×
,, scalaris, *Sow.*			×	×	
Productus semireticulatus, *Martin*	×	×	×	×	×
,, scabriculus, *Martin*	×	×	×	×	×
Chonetes laguessiana, *de Kon.*	×	×	×	×	×
Spirifer biaulcatus, *Sow.*	×	×	×	×	
,, glaber, *Martin*	×	×			
,, Urei, *Flem.*		×	×	×	×
Orbiculoides (= Discina) nitida, *Phil.*	×	×	×	×	×
Lingula mytiloides, *Sow.*	×	×	×	×	×
,, squamiformis, *Phil.*	×			×	×

convenient to describe its local development in different districts under the following heads :—

1. Bristol and South Wales.
2. Devonshire.
3. Midland area.
4. Cheshire and Lancashire.
5. Derbyshire and Yorkshire.
6. Durham and Northumberland.
7. Scotland.
8. North of Ireland.
9. South of Ireland.

1. *Bristol and South Wales*

Millstone Grit.—This division consists of fine-grained quartzitic sandstones of a yellowish colour with iron-stained spots. It surrounds the Bristol and Somerset coal-field, where its thickness is probably about 500 feet,[a] but is in most places hidden by the Triassic beds, only coming to the surface at a few places, as near Bristol and near Chipping Sodbury. To the west of the Severn these sandstones are very much thinner. In the Forest of Dean they are stated to be 470 feet thick, the lower, 100 feet only, being fine-grained, and the rest of coarse grain. In South Wales the group is described by Mr. Strahan as consisting of three members which vary much in thickness; the lowest beds are pebbly grits, which are thickest along the northern outcrop, but do not exceed 80 feet, thinning away to the south-east; in the centre are shales from 100 to 300 feet, and at the top massive sandstones, which are called "Farewell Rock" by the miners, because no workable seams of coal lie below it. This rock varies from 40 to 80 feet, and the whole group is on the average about 250 feet[26] (see Fig. 82).

Lower Coal-Measures.—This division is mainly argillaceous, consisting principally of shales with many seams of coal, and many of the shale bands contain ironstone nodules, so that these measures are rich in coal and iron. In the Bristol field the thickness is about 2000 feet, and it includes several thick beds of sandstone. In the central part of the area (east of Bristol) there are thirty-six coal-seams, but many of these are thin and disappear both to the north and south. In the Forest of Dean the equivalent beds are about 1900 feet thick, with fifteen seams of coal.

In the South Wales coal-field the lower Coal-measures vary much in thickness, from about 850 feet near Pontypool to 1600 in the Taff valley; at the latter locality there are twenty-two seams of coal. There are also many bands of ironstone nodules (carbonate of iron) which were formerly worked, but this industry is not active at the present time.

[a] According to Professor Lloyd Morgan of Bristol, who tells me that the thickness has been over-estimated.

Fig. 81.—DIAGRAMMATIC SECTION ACROSS THE BRISTOL COAL-FIELD (Professor E. Hull). Distance about 15 miles.

5. Inferior oolite
4. Upper lias
3. Middle lias
2. Lower lias
1. Keuper marls
} Neozoic rocks.

D. Coal-measures and Pennant grit
C. Millstone grit
B. Carboniferous limestone
A. Old Red Sandstone
} Palæozoic rocks.

Fig. 82.—SECTION ACROSS THE COAL-FIELD OF SOUTH WALES (Professor E. Hull). Distance about 30 miles.

A_3. Upper Coal-measures.
A_2. Pennant grits.
A_1. Lower Coal-measures.

B. Millstone grit and black shales.
C. Carboniferous limestone and lower shales.
D. Old Red Sandstone.

Pennant Grit.—This is a sandstone group, the prevalent material being a hard, gray, gritty, felspathic sandstone, which makes a durable building stone and lies in thick beds, so that it can be cut as a freestone. In the Bristol coal-field it is from 1000 to 1700 feet thick, and includes four workable seams of coal. In the Forest of Dean there are 830 feet of sandstones with thin coals, which probably represent the Pennant grits.

In South Wales this group consists of massive felspathic grits with some subordinate bands of shale, and it forms the greater part of the high central moorland plateau, which is known as the Mynydd. Near Pontypool on the east it is only about 800 feet thick, and the coal-seams are thin, but to the west of Taff Vale the group rapidly thickens and workable coals set in, so that near Swansea it is over 3000 feet thick and contains fifteen seams of coal.

Upper Coal-Measures.—This is a variable series of gray shales, light-coloured sandstones, and coals. It is locally known as the Upper Coal-measures, but is probably equivalent to the upper part of the Middle Coal-measures of more northern coal-fields.

In the Bristol coal-field a thickness of about 2000 feet is found, although the summit is nowhere seen; it is divided into two parts, the lower portion or Farrington group occurring in both the northern and southern basins, the upper portion or Radstock group only coming into the southern or Somerset basin.

In South Wales, near Swansea, the group is still thicker, and has been estimated at about 3000 feet (Pellengare series), and if the Llanelly coals are above this, the total will be nearer 4000 feet.

All the coal-seams in South Wales undergo a change of character as they are followed from east to west, the seams which are bituminous house-coals in the east becoming hard steam-coals in the central parts of the basin and passing westward into stone-coal or anthracite. It is also found that the coals of the upper measures are more bituminous than those of the lower.

2. *Devonshire*

In Devon the whole Carboniferous series has been called the "Culm-measures," but this name would be more appropriately restricted to the higher portions, in which the beds of "culm" or hard impure coal occur. The Lower Culm-measures were described on p. 216. There is nothing that exactly corresponds to the Millstone Grit, but it is possible that this and the Lower Coal-measures of Somerset are represented in the Middle Culm-measures of Devon. According to Mr. Ussher[27] this middle group is

characterised by the occurrence of rather hard sandstones of gray lilac and brown tints in beds from four to five feet thick, associated with marly shales and red and gray mudstones; there are also occasional beds of hard coal or anthracite. Ferns and other plants occur, but few other fossils have been found. These beds occupy much of the eastern part of the culm area, and on the north they extend to the coast between Westward Ho and Portledge Mouth, while on the southern side they pass by Morchard and Hatherleigh to the coast near Bude. In consequence of the intense plication of the whole area, no estimate of thickness has yet been found possible.

At and west of Exeter they present rather a different facies, the grits being in thinner beds and alternating regularly with hard splintery shales, but the sandstone facies comes on again to the southward between Chudleigh and Newton Abbot, where some of the beds are conglomeratic and rest with apparent unconformity on the cherty beds. In one of these conglomerates rolled pebbles of chert occur, and fragments of a granite which, however, is not like that of Dartmoor. It seems probable that these sandstones really belong to a higher horizon than the Exeter beds, and that they overlap the latter southwards so as to rest on the Lower Culm, for similar beds occur also south of Newton Abbot, and outliers of them are found near Plymouth, Saltash, and Beer Alston, resting directly on Upper Devonian rocks. Thus there may be a break and unconformity between the Lower and Middle Culm-measures.

The Upper Culm-measures or Eggesford Grits are exposed on the coast near Clovelly and near Eggesford, in the Torridge valley. They consist of hard, fine-grained grits of dark gray and lilac colours in regular beds, with occasional layers of dark gray shale. Plant remains are the only fossils.

3. *The Midland Area*

In the central part of England the Lower Carboniferous series is either very thin or absent, and the Coal-measures often rest directly on the older rocks. These measures come to the surface in several districts and form coal-fields, which pass under and are surrounded by the Permian and Triassic rocks, but it is noteworthy that the greater part of the beds which were formerly regarded as Permian are now referred to the Upper Coal-measures.

The area will be regarded as including the coal-fields numbered 4, 5, 6, 9, 17, and 18 on p. 243; the only complete succession of the Upper Carboniferious series is to be found on the western and

eastern borders of the area, near Coalbrookdale in Shropshire on the one hand, and in Leicestershire on the other. Towards the centre, and everywhere in passing from north to south, the lower stages are overlapped by the higher.

In the Coalbrookdale coal-field near Wellington and Shifnall the succession is as follows :—

		Feet.
Upper C.M.	Red and purple sandstones and marls	about 800
	Mottled clays and greenish grits, with a limestone containing *Spirorbis carbonarius*	440
Middle Coal-measures, with coals and ironstones, with a band containing marine fossils		600
Lower Coal-measures, if present		not more than 100
Millstone Grit, thinning out southward		from 0 to 80
		About 2000

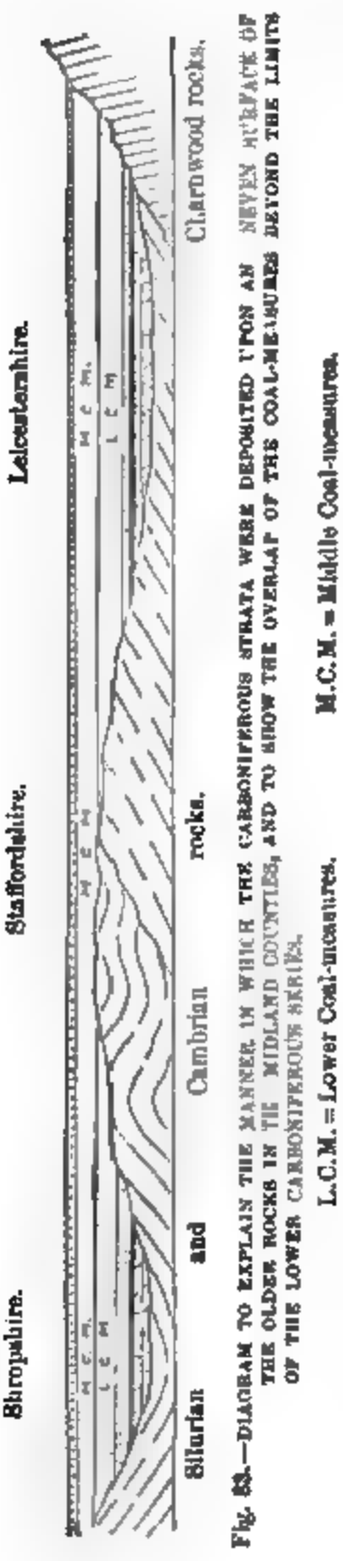

Fig. 83.—DIAGRAM TO EXPLAIN THE MANNER IN WHICH THE CARBONIFEROUS STRATA WERE DEPOSITED UPON AN UNEVEN SURFACE OF THE OLDER ROCKS IN THE MIDLAND COUNTIES, AND TO SHOW THE OVERLAP OF THE COAL-MEASURES BEYOND THE LIMITS OF THE LOWER CARBONIFEROUS SERIES.

M.C.M. = Middle Coal-measures.
L.C.M. = Lower Coal-measures.

An interesting fact connected with this district is the existence of a break and unconformity between the Middle and the Upper measures, the older group having been flexured and extensively eroded before the deposition of the upper measures, so that the former lie in a broad syncline, while the latter are nearly horizontal, the basement bed of this upper group being a mottled clay known as "calaminker," overlain by a bed of gravel or conglomerate called the Rough Rock (see Fig. 84).

As the lower members of the series are traced southward it is found that the Millstone Grit gradually thins out and disappears, so that in Worcestershire the Coal-measures rest directly upon the Old Red Sandstone, extending southward in a narrow tract which broadens out near Bewdley. Moreover, these measures chiefly belong to the uppermost stage, which has therefore overlapped all

those below. The same overlap appears to take place both in a westerly and easterly direction from Coalbrookdale; thus near Shrewsbury we have upper Coal-measures only resting on Silurian and Cambrian rocks, while eastward, in South Staffordshire, the middle group, which occurs in the northern part of that coal-field, is overlapped southward by the upper group. This latter is very thick in Staffordshire, and the succession south of Dudley is as follows:[28]—

		Feet.
Upper	Red sandstones and marls (Hunnington) . .	1300
	Gray sandstones and marls (Halesowen) . .	800
	Red marls and greenish sandstones . . .	800
Middle or productive Coal-measures . . .		500 to 800
		3700

The Upper Coal-measures contain only a few thin coal-seams,

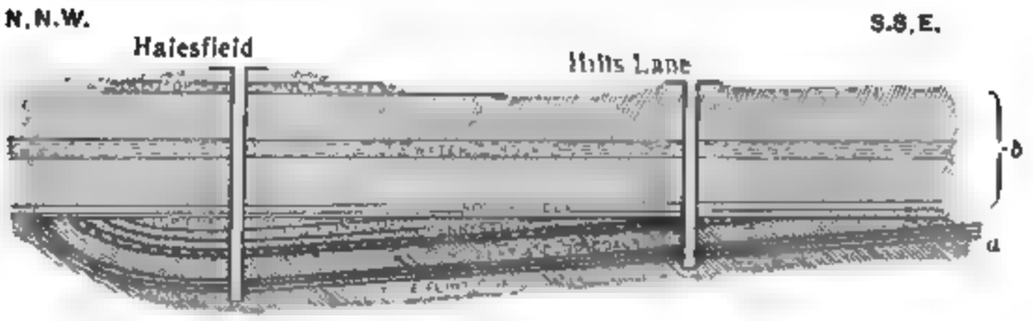

Fig. 84. DIAGRAM SECTION ACROSS THE MADELEY DISTRICT, COALBROOKDALE (W. J. Clarke).

b. Upper Coal-measures. *a*. Middle Coal-measures.

but there is a Spirorbis limestone near the top of the Halesowen group. The sandstones of the productive measures are always gray or white, and these beds contain many good coal-seams, including the "thick coal," which is from 25 to 30 feet thick, but this is really a compound seam, for it splits up northward into fourteen separate seams with intercalated measures amounting to a total thickness of about 300 feet.

In Warwickshire the beds are similar, the productive measures having a thickness of 600 to 700 feet, and containing five workable coal-beds near the centre, which coalesce toward the south into one compound seam 26 feet thick. These beds are succeeded by Upper (red) Coal-measures, which are divisible into three divisions comparable with those of Staffordshire. There is in fact every probability that the two coal-fields are connected beneath the newer rocks of the Birmingham district and are really parts of a single basin.[29]

In Leicestershire the succession is different and the thickness of productive Coal-measures is much greater. Near Ashby-de-la-Zouch the sequence is :—

	Feet.
Upper C.M., coarse grits in unconformable outliers .	50
Middle C.M. with ten coal-seams	1500
Lower C.M., sandstones and shales without coals . .	1000
Millstone Grit	50
	2600

4. *Cheshire and Lancashire Basin*

For the purposes of description the coal-fields of North Staffordshire, Lancashire, Flint, and Denbigh will here be treated as parts of one great basin, for there is little doubt that they are continuous from west to east beneath the Triassic plains of Cheshire (see Fig. 85). The following is the general sequence in this area :—

		Feet.
Upper C.M.	Red and purple sandstones and marls with some gray beds and thin limestones .	2200
Middle C.M.	Gray shales and sandstones with many seams of coal and ironstone . . .	3500
Lower C.M.	Gray flagstones and black shales with some coal-seams (generally thin) . .	1000 to 1800
Millstone Grit	Sandstones and shales, thickening toward the N.E.	400 to 3500
Pendleside group	Dark shales with a lenticular limestone thickening to the N.E. . . .	450 to 1500
		12,500

Pendleside Group.—The relations of this group have been described on p. 222. It is a local set of beds which set in near Congleton in North Staffordshire, attains a thickness of 2500 feet in the Clitheroe and Pendleside district, but seems to die out in Yorkshire.

A similar set of beds occupies the same position on the western side of the area in North Staffordshire, where they include one or two bands of volcanic tuff. They are well exposed in Congleton Edge, and have recently been described by Messrs. Gibson and Hind, from whose paper Fig. 87 has been borrowed. Their thickness here is about 250 feet.

All the limestones of the Pendleside group are black, and they contain a different fauna from that of the underlying limestones, their characteristic fossils being *Goniatites reticulatus*, *Posidonomya Becheri*, *Posidoniella lævis*, and *Aviculopecten papyraceus*—fossils which do not occur in the Clitheroe limestones nor in the Yoredale

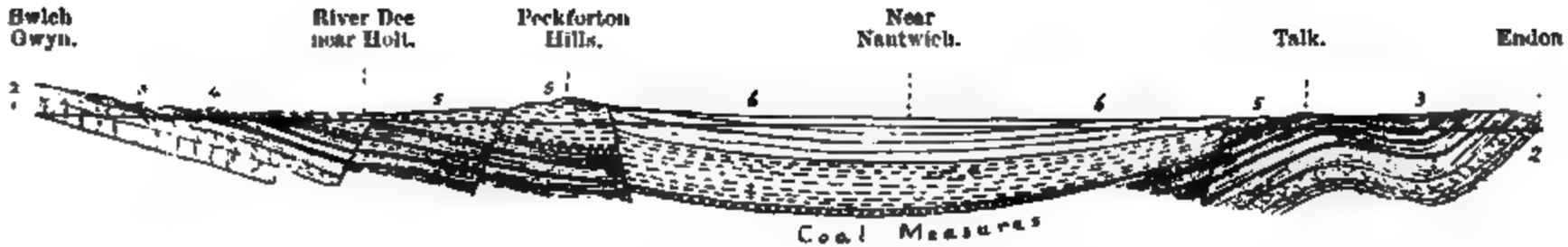

Fig. 85.—SECTION ACROSS THE CHESHIRE BASIN FROM NEAR WREXHAM IN DENBIGH TO ENDON IN STAFFORDSHIRE. Distance 42 miles.
Reduced from section by Sir A. Ramsay, prepared for the Coal Commission Report.

6. Triassic marls (Keuper).
5. Triassic sandstones (Bunter).
4 and 3. Coal-measures.
2. Millstone Grit.
1. Carboniferous Limestone.

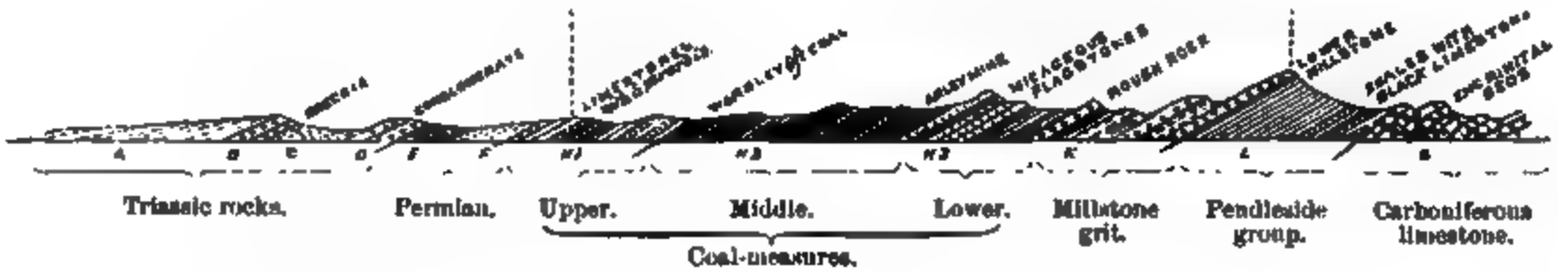

Fig. 86.—GENERAL SECTION ACROSS THE CARBONIFEROUS SYSTEM IN SOUTH LANCASHIRE (from the *Coal-fields of Great Britain* by Professor E. Hull). Distance about 18 miles.

Beds, but do occur in all the shales which lie between the Millstone Grits, and range also into the Lower Coal-measures. Consequently it seems necessary to dissociate them from the Carboniferous Limestone series.

The Millstone Grit consists of several sets of grits and flagstones separated by shales of varying thickness. Its thickness increases to the northward, and finds its maximum in East Lancashire, where it is said to be over 3500 feet thick. Through-

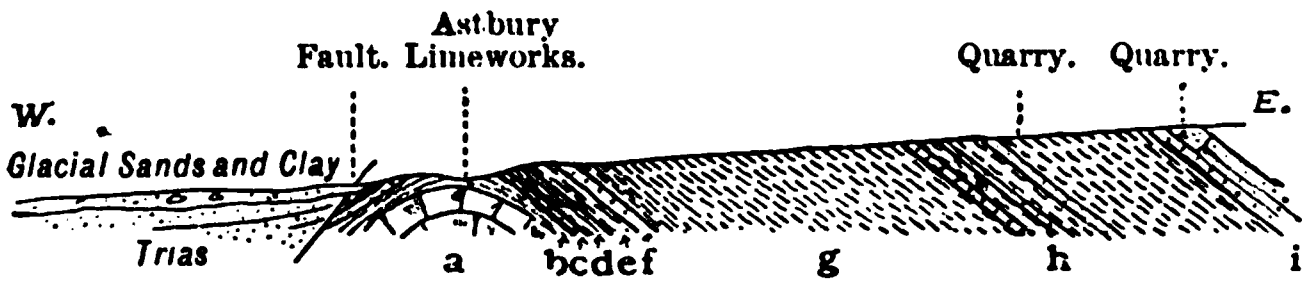

Fig. 87.—SECTION THROUGH CONGLETON EDGE (W. Gibson and W. Hind).

h, i. Millstone grits. b to f. Grit, tuff, limestone, and shales.
g. Pendleside shales. a. Carboniferous limestone.

out the North Derbyshire and Lancashire area the following subdivisions can be traced, though the thickness of each varies greatly :—

5. Rough Rock, or first grit.
4. Shales.
3. Middle grits, including the second and third grits.
2. Shales.
1. Kinderscout grit, or fourth grit.

The lowest grit takes its name from the high table-land of Kinderscout in the Peak country, which consists of this rock, and rises to a height of 2000 feet above the sea. The middle grits are not so continuous as the upper and lower, but come in as lenticular beds at different horizons. The Rough Rock is a very coarse grit, sometimes passing into a conglomerate of small quartz pebbles. In Lancashire it contains a workable coal-seam called the "Feather-edge coal." The shales below also include thin seams of coal. To the south-west in Staffordshire the middle grits thin out, but the fourth grit appears to be represented on Congleton Edge by a set of grits and shales about 500 feet below the third grit, so that the group here is not less than 1000 feet thick, and has the Pendleside shales below it. Between Biddulph and Macclesfield the other grits come in and thicken rapidly northward, till near Mottram the whole group is 2500 feet thick, and near Burnley over 3000.

Lower Coal-Measures.—These are sometimes called the Gannister measures, *gannister* being the miners' name for a peculiar hard and compact siliceous stone which often forms the floors of the coal-

seams. Hard gray flagstones are the predominating beds in this division, with subordinate bands of shale. The coals are generally thin, but two or three running from three to four feet thick are often worked. In the vicinity of the coal-seams plant remains are abundant, but the fossils in the other beds are generally marine forms, the chief of which are mentioned on p. 251.

In Flintshire and North Staffordshire these lower measures are about 1000 feet thick, but they increase northward and reach 1800 feet in Lancashire, where they are well exposed in the cuttings of the Wigan and Liverpool Railway.

Middle Coal-Measures.—This is a more varied series of gray shales and sandstones, and from the numerous beds of coal and ironstone it is commercially the most important group in the whole series. These measures attain their greatest thickness in North Staffordshire, where they are about 3500 feet, with forty coal-seams. In Flint and South Lancashire their thickness is much less, but they seem to thicken rapidly in an easterly or north-easterly direction—that is to say the sedimentary material thickens, for the total thickness of coal does not alter so much. The following table is taken from Mr. Morton's *Geology of Liverpool* (second edition, pp. 35 and 49):—

	Flint.	Prescot.	St. Helens.	Wigan.
	Feet.	Feet.	Feet.	Feet.
Thickness of coal-seams . .	50	61	83	72
Associated strata . . .	650	1259	1655	2106
Total . .	700	1320	1738	2178

The fossils of the middle measures are chiefly of terrestrial and freshwater organisms — fish, such as *Palæoniscus Egertoni*, *Megalichthys Hibberti*, and *Rhizodus incurvus*; Unio-like bivalves, as *Carbonicola acuta*, *C. robusta*, *C. aquilina*, *Anthracomya modiolaris*; numerous ferns, especially *Sphenopteris* and *Neuropteris*, and other plants, such as *Calamites varians* and *Calamocladus equisetiformis*. Two marine bands have been found in North Staffordshire and another in Lancashire, and these have yielded the fossils mentioned on p. 251.

Upper Coal-Measures.—This division has been recently studied by Mr. W. Gibson, who comes to the conclusion that the red and purple sandstones which were formerly referred to the Permian must be included in the Carboniferous.[30] To these he gives the name of Keele "series," but it would be better to call them the

Keele Beds, and they form the highest of the four groups which he recognises in North Staffordshire and Denbigh. The following brief account is taken from Mr. Gibson's paper :—

		Feet.
Keele Beds	Red and purple sandstones and marls with three thin layers of Spirorbis limestone. Fossils, a few plants and Entomostraca . .	700
Newcastle under Lyme group	Gray sandstones and shales with four thin seams of coal and a limestone at the base. Fossils, many ferns and plants (*Sigillaria Brardi*)	300
Etruria Marls	Red and purple marls and clays with thin bands of green grit and a limestone near the base. The clays are largely used for pottery . . .	800
Blackband group	Gray sandstones and marls with blackband ironstones and thin seams of coal. *Anthracomya Phillipsi* and fish teeth . . .	300 to 450
		Total about 2200

There is a similar set of beds near Manchester, which have not yet been correlated with the above, but are described as follows:—

	Feet.
Reddish clays, shales, and sandstones, with six beds of gray limestone and two thin coal-seams . . .	600
Red and gray clays, shales, and flagstones . . .	600
Gray and black shales and sandstones with six coal-seams	710
	1910

5. *Notts, Derby, and Yorkshire*

This coal-field forms a continuous tract on the eastern side of the Pennine hills, from a little north of Nottingham to a little north of Bradford and Leeds, a distance of about sixty miles. It is bounded on the west and north by continuous ridges of Millstone grit, and in all probability the exposed coal-field is only part of a large basin-shaped area, the eastern lip of which is concealed beneath the Permian and Triassic rocks. In the southern part of the area the prevalent dips are eastward, and no Upper Coal-measures are exposed, but near Wakefield beds referable to the upper division come in, and the strata begin to rise toward the north-east. There is no doubt that the Coal-measures were originally continuous with those of North Staffordshire and Lancashire across the intervening anticline, just as the Millstone Grits are still continuous between Lancashire and South Yorkshire.

Millstone Grits.—These beds have been described on p. 260, and as on the west, so also on the east the grits are thickest in the

northern part of the area (3500 feet), thinning very greatly toward the south. The lowest or Kinderscout Grit forms the escarpment of Derwent Edge, the Chatsworth and Rivelin Grits belong to the third Grit, and the highest or "Rough Rock" is well seen in Stannedge quarries near Chesterfield.

The Lower Coal-Measures resemble those of Stafford and Lancashire, thickening northward from 900 feet in Notts to 1600 feet in Yorkshire. They consist largely of flagstones, but include beds of gannister and fireclay, and several thin but workable beds of coal. The fossils are chiefly marine.

The Middle Coal-Measures are from 2000 to 3000 feet thick, and are so entirely like those of Lancashire that several of the Yorkshire coal-seams can be identified with their counterparts on the west; thus the "silkstone" of Yorkshire is the "Arley mine" of Lancashire. Layers of nodular carbonate of iron are frequent and have been largely worked. Some of the Coal-measure sandstones near Pontefract, Ackworth, and Rotherham in Yorkshire are stained red, and were formerly mistaken for beds of Permian age.

Upper Coal-Measures.—These are concealed beneath the newer rocks in the southern part of the area, but have recently been proved in a boring at Thurgarton, near Southwell in Notts. The cores indicate a succession like that of North Staffordshire, but with a less thickness. Mr. W. Gibson (*op. cit.* p. 262) gives it as follows :—

		Feet.
Permian (Marl Slate).		
Keele Beds	Red sandstone and marl with *Neuropteris rarinervis* and *Pecopteris Miltoni*	188
Newcastle Beds	Gray sandstones and shales with a seam of coal	91
Etruria Marls: red marls and green grits		257
Gray Coal-measures below.		

In Yorkshire near Rotherham there are some red marls and sandstones which are classed as upper Coal-measures, and probably belong to the Etruria marls, but only 54 feet of them are seen.

6. *Durham and Northumberland*

This area, sometimes called the Newcastle coal-field, extends from the northern side of the Tees valley west of Darlington to the mouth of the river Coquet, a distance of about 60 miles. It is limited on the south by an anticlinal flexure which runs from Barnard Castle to the mouth of the Tees, and in Northumberland the Millstone Grit runs into the sea near Alnmouth, so that the

eastern part of the coal-field passes beneath the floor of the North Sea.

Millstone Grit.—This division is of small thickness, and it is doubtful what beds should be assigned to it. In Yorkshire the Millstone Grits thin rapidly as they are followed northward, and in the North Riding are not more than 600 feet thick. Some of the grits, however, are believed to come in again between Teesdale and Tynedale, and have been mapped as forming broad plateaus on the high fells of West Durham, but in this area they lose their coarse gritty character and become indistinguishable from the sandstones and flagstones of the Gannister measures.

Lower Coal-Measures.—These beds likewise become much thinner in a northerly direction, so that in Northumberland the whole thickness between the Felltop limestone and the Brockwell coal, which is the lowest workable seam, is only about 350 feet. Of this Mr. Lebour assigns 150 feet to the Gannister measures, and in this thickness there are two seams of coal. A few marine fossils such as *Aviculopecten papyraceus* and stems of crinoids have been found in these beds.

The Middle Coal-Measures maintain their thickness, which in Durham is estimated at 2000 feet, and they contain some twenty good seams of coal, including the Brockwell seam at the base, and the High Main seam, which is the highest known seam in the series. Besides these there are many minor or less valuable seams, bringing the total number to over sixty. Some of the shales contain nodules and bands of ironstone which have occasionally been worked, and some of these are so full of *Carbonicola* shells that they are known as "mussel bands." The sandstones are used for building purposes, and one bed, known locally as the "grindstone post," furnishes the celebrated Newcastle grindstones.

Upper Coal-Measures.—It is uncertain whether these occur within the exposed area of the coal-field. Professor Hull separated the highest 900 feet of Coal-measures under this head because they consist largely of sandstones and contain few beds of coal. There are, however, four seams, and one of them is four feet thick. The sandstones too are gray, and the beds are certainly not comparable to the red measures of the Midland counties.

7. *Scotland*

The Upper Carboniferous series is not so fully developed in Scotland as it is in England, and the thick middle division of the Coal-measures, which is the most productive part of the English series, appears to be absent north of the Tweed. The Coal-measures

occur in several basin-shaped tracts, the chief of which are those in Midlothian and Fife on the east, of Lanark in the centre, and of the Clyde basin on the west.

Millstone Grit.—In the counties of Edinburgh, Fife, Stirling, and Lanark the upper limestones are succeeded by a set of pale red and yellow sandstones, in thick beds with occasional layers of shale. This group of sandstones is generally known as "Moorstone Rock," but has also been called the Rosslyn sandstone, from its fine exposure near that place. Its thickness near Edinburgh and north of the Forth is from 350 to 600 feet, but it thins from the north-east to south-west; in Lanark it is only from 90 to 100 feet, and farther west, in Ayrshire, it is so thin as not to be definitely separable from the Coal-measures. Fossils are rare, but a few of marine species have been found.

Lower Coal-Measures.—These measures attain a considerable thickness, about 1200 feet in Fife and Midlothian, from 1200 to 1500 in Lanark, and about 1300 in the Clyde basin. They consist of gray and white sandstones, with shales, coals, fireclays, and ironstones, and ten of the coal-seams are from 2 to 5 feet in thickness. In Lanark and the Clyde basin the base of the series is taken at the slaty-band ironstone, and there are several other continuous beds of blackband ironstone which are of much commercial importance.

These measures contain a flora which is pronounced by Mr. R. Kidston to be the same as that of the Lower Coal-measures of England. The commonest plants are *Neuropteris Loshi*, *N. giganteus*, and *Sphenopteris latifolia*. They also include two marine bands, one near the base containing *Schizodus deltoideus*, *Conularia quadrisulcata*, *Lingula mytiloides*, and *Orbiculoidea nitida*; and another above the "Ell" coal containing the same *Conularia* and *Orbiculoidea* with *Productus scabriculus*, *Bellerophon Urei*, and *Aviculopecten papyraceus*.

Upper Coal-Measures.—These consist chiefly of red sandstones, clays, and shales, their thickness varying in different places with a maximum of 900 feet in Fifeshire. They rest unconformably upon the Lower Coal-measures, which appear to have been tilted, and in some places slightly flexured, before the deposition of the upper measures—a fact which may account for the absence of the middle measures.

In Fife this group comprises red sandstones, red and purple clays, with some thin seams of coal and ironstone; a tongue of these beds is prolonged eastward beyond the normal boundary to the coast near Lower Largo, where the beds are pierced by two necks filled with volcanic agglomerate, a fact which shows that some of the Fifeshire volcanoes were of post-Carboniferous date.

In Ayrshire the unconformity at the base of these measures is

very marked, for they steal across the outcrops of the Lower Coal-measures until they rest on the uppermost limestone of the Lower Carboniferous, the Millstone Grit being absent as above stated. In the Ayr coal-field these beds include a thin band of fine white limestone containing *Spirorbis carbonarius*, the existence of which serves to connect them closely with the English Upper Coal-measures. A few Coal-measure plants have also been obtained from them.

8. *Ireland*

Rocks of Upper Carboniferous age occur in several parts of Ireland, but the principal coal-fields are four in number, two in the north and two in the south. Of these the following is a brief account.

Southern Counties.—One extensive area occupies parts of the counties of Clare, Limerick, Kerry, and Cork, but the coal-seams in this region are few and of variable thickness, so that commercially it is less important than the "Leinster coal-field," which occupies parts of Tipperary, Kilkenny, and Queen's County. The succession in both these areas is similar, but a greater thickness of the middle Coal-measures comes into the western basin. The groups recognised are :—

	Munster.	Leinster.
4. *Middle Coal-measures* with several good seams of coal. Fossils are freshwater Mollusca, Crustacea, and Amphibia	2000	800
3. *Lower Coal-measures* with thin coals and shale roofs containing marine shells	900	600
2. *Flagstone group*, micaceous flagstones and shales .	500	300
1. *Black Shale group* with *Glyphioceras sphæricus*, *Aviculopecten papyraceus*, *Posidonomya Becheri*, and *Lunulacardium Footi*	600	500
	4000	2200

The Black Shale group has been called "Lower Coal-measures" by Mr. Kinahan, but this is a misnomer, for there are no coals in it, and it underlies the representative of the Millstone Grit; at the same time its fossils show that it is not the equivalent of the Yoredale Beds, but of the Bowland Shales and Pendleside group of Lancashire (see p. 258).

The Flagstone group is the equivalent of the Millstone Grit of Bristol and South Wales, and the true Lower Coal-measures are the beds which overlie these flagstones, many of the same marine shells occurring in them as in the Gannister Beds of Northern England.[30]

The Jarrow collieries in Queen's County are known for the number of Amphibian remains which have been obtained from them.

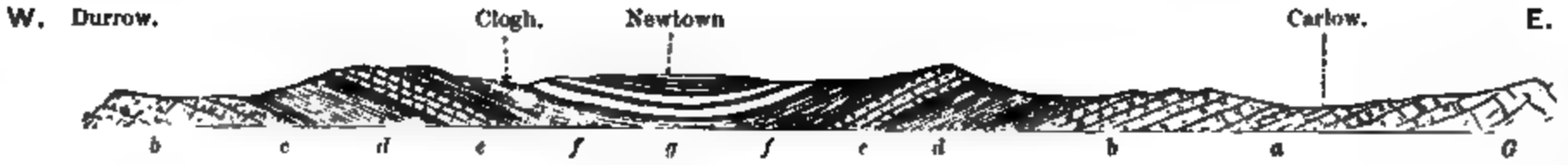

Fig. 88.—SECTION ACROSS THE CASTLECOMER COAL-FIELD IN LEINSTER (Professor Hull). Distance 22 miles.

g. Middle Coal-measures
f. Lower Coal-measures
e. Flagstone group
d. Black shale group
} Upper Carboniferous Series.

c. Upper
b. Middle
a. Lower
} Carboniferous Limestone.

G. Granite of Carlow.

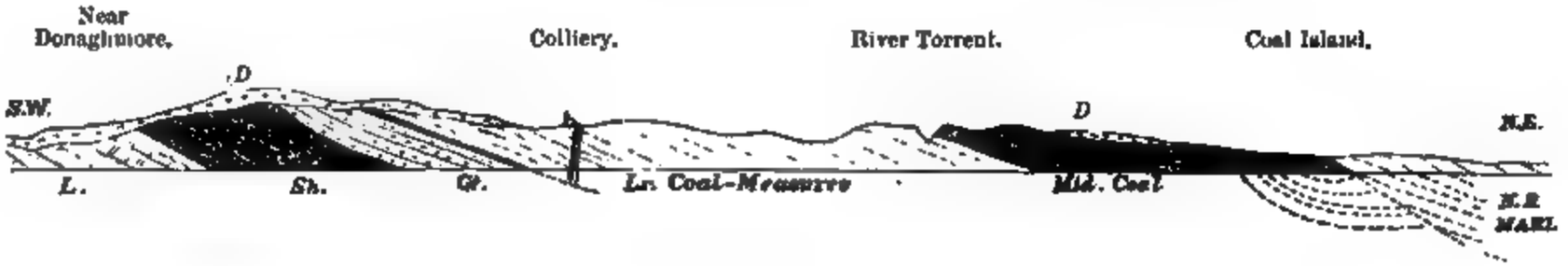

Fig. 89.—SECTION ACROSS THE COAL-FIELD OF TYRONE (from Professor Hull's *Coal-fields of Great Britain*). Distance about 5 miles.

L. Carboniferous Limestone.
Sh. Black shales = Pendleside group.
Gt. Millstone Grit.
Lr. Lower Coal-measures.
M.C. Middle Coal-measures.
N.R. Triassic Marls.
D.D. Glacial Drift.

Northern Counties.—The most important tract in the north is the Tyrone coal-field, which lies to the north of Dungannon and contains many good seams of bituminous coal. The succession as given by Mr. Hardman [31] is as follows :—

	Feet.
Middle Coal-measures.—Soft sandstones and shales with coals, fireclays, and ironstones . . .	930
Lower Coal-measures.—Hard sandstones and shales with a few thin coals and ironstones . . .	1000
Millstone Grit.—Coarse grits and sandstones .	60 to 200
Black shales with some sandstones, marine fossils .	600
	About 2600

Upper Carboniferous rocks occupy a considerable area in the counties of Leitrim and Fermanagh, and their sequence is the same as in Tyrone, but only part of the Lower Coal-measures come in above the Millstone Grit, three thin coals occurring in a thickness of about 450 feet.

Foreign Equivalents

It is unnecessary to give detailed accounts of the Upper Carboniferous rocks which occur in France, Belgium, and Germany, inasmuch as they resemble more or less the English series, the only important point of difference being that no such division as our Millstone Grit is recognised in any of these countries.

In Russia, however, there is a complete change of facies, for there the whole upper division is a marine formation, consisting mainly of limestones with some marls and shales. Most of the limestones consist largely of foraminifera, especially the large *Fusulina cylindrica*, and contain *Productus semireticulatus*, *P. cora*, *Orthotetes crenistria*, and other western species, together with Asiatic forms, such as *Productus timanicus*, *P. tuberculatus*, *Orthotetes eximius*, *Chætetes radians*, and a screw-shaped Bryozoan *Archimedipora*. This marine Upper Carboniferous is found again in India and China.

Physical and Geographical Conditions

The records of the Carboniferous period in the British Islands being more complete than those of earlier times, we are able to construct a more accurate geographical picture or map of the region, and can indicate with greater certainty the general changes which took place in the course of the period. Having treated the stratigraphy of the two great divisions of the system separately, it will be convenient to adopt the same plan in dealing with the conditions under which the rocks were accumulated.

1. *Lower Carboniferous Epoch*

It is clear that the Carboniferous period was ushered in by the partial submergence of the great continent which included the larger part of Britain during the preceding Devonian period, and in attempting to reconstruct the geographical conditions which were established during the earlier part of the period certain salient facts and certain inferences at once present themselves. (1) There is a large area, comprising the southern half of Scotland, the north-east of England, and the extreme north of Ireland, in which a great thickness of shallow-water deposits were accumulated. (2) There is another large area, including the greater part of Ireland, the northern part of England from Westmoreland to North Staffordshire, Derby, and Leicester, together with a tract in South Wales and Southern England, where a maximum amount of limestone was formed—limestone in which corals, crinoids, and shells are abundant. Such material indicates clear water, and clear water means a sea which, if not far from land, is far from the mouths of any large rivers. (3) The fact that in the extreme south-west of Ireland the Carboniferous limestone is replaced by a thick mass of shales with occasional beds of sandstone, which may be taken to indicate that this part of the sea was traversed by a mud-bearing current carrying the finer detritus from some land lying to the west or south-west, the small thickness and fine grain of the Coomhola grits showing the land to be so far away that it was only occasionally, when perhaps the rivers were in flood, that the current had power enough to carry sand into that part of the sea. (4) In Devon and Cornwall the limestones are thin and discontinuous, but are associated with some thickness of radiolarian chert. From the occurrence of the radiolaria it has been claimed that the sea in which they lived must have been very deep and comparable to the oceans of the present day. It is doubtful, however, whether the facts warrant this inference any more than in the case of the chert beds of the Ordovician period (see p. 131), for the associated rocks do not resemble the modern oceanic oozes and red clays either in colour or in structure. There is no good reason for supposing that the water in which these lower culm measures were accumulated was deeper than any other part of the Carboniferous sea. (5) There was an area of no great width but of some length, crossing the central parts of Wales and of England, over which no rocks of Lower Carboniferous age were formed, and which we may consequently consider to have been dry land during this epoch. (6) The small thickness of the Lower Carboniferous in Anglesey, where it consists of basal beds of red sandstone and

conglomerate, overlain by only 450 feet of limestone, taken in connection with the indications of a shore line in Dublin and Carlow, suggests that the land extended across the Irish Sea and included parts of Wicklow and Wexford.

We thus get a picture of a broad sea covering the greater part of the British Isles and extending southward over parts of the island and over the north of France, for Lower Carboniferous beds occur in Brittany, Normandy, the Boulonnais, and Belgium. In the centre of this sea was an island some 300 miles in length, but of no great breadth, and not large enough to give birth to any large river, so that the sea all round it was generally clear and teemed with marine life. It was only occasionally that parts of this sea were invaded by mud-bearing currents, such as must have brought the material of the shales in the middle of the limestone series at Bristol and of the "calp" shales in Ireland.

When, however, we pass northwards through Yorkshire we find the limestones thinning out and gradually replaced by a series of shales and sandstones which can only have been formed from the detritus of a large area of land. The contrast between the limestone facies of Cumberland and the arenaceous facies of Northumberland points to the north-east as the direction from which the terrestrial sediment came. This suggests the existence of a large tract of land over what is now the northern part of the North Sea. This land probably extended westward through the Highlands of Scotland and eastward through Norway and Sweden, where no Carboniferous rocks occur; and it is clear that this land was drained by large rivers, one or two of which emptied their mud and sand-laden waters into the northern part of the Carboniferous sea—that portion of it which lay over and east of Scotland, having probably the form of a shallow and land-locked bay. It is only in such a bay, and in the neighbourhood of continental land, that such a thick mass of sediments could be laid down, and the subsidence which permitted of its accumulation must have been slow but long continued.

In the western part of this bay were several smaller islands, which must gradually have diminished in size as subsidence went on. The central part of the southern uplands of Scotland formed one of these islands; the Lake District was another, and a third seems to have existed in County Down (Ireland), but this may have been connected with the southern island. For the probable history of these islands the reader is referred to the author's *Building of the British Islands* (Bell and Sons, 1892).

In conclusion it may be remarked that the sea of the Carboniferous limestone was not an open sea or ocean, but an enclosed sea

comparable to the Mediterranean or Caribbean seas of the present day. There are, indeed, many striking points of comparison between this picture of the British Carboniferous sea and the existing West Indian and Mexican seas. The latter form a westerly embayment of the modern Atlantic Ocean; they are divided into the Caribbean Sea and the Gulf of Mexico by a chain of islands. Around these islands deposits of a purely calcareous character are being formed, and large fields of crinoids flourish between depths of 100 and 500 fathoms. Other calcareous deposits are accumulating in the southern part of the Gulf of Mexico, while its northern part receives the muddy sediment brought down by the waters of the Mississippi. Beyond this the parallel fails, for no part of the Carboniferous sea is likely to have been as deep as the central part of the Caribbean.

2. *Upper Carboniferous Epoch*

We have next to consider what is likely to have been the nature of the change which put an end to the formation of the Carboniferous limestone and led to the accumulation, first of the *Posidoniella* shales and Millstone grits, and afterwards of the Coal-measures. Here again we may adopt the plan of pointing out certain salient facts and what may be inferred therefrom.

(1) We have seen that the Lower Carboniferous was a time of subsidence, and that the sequence of beds was in most places from sandstones through shales to limestones; when, therefore, in passing from the Lower to the Upper Carboniferous we find a reversed sequence of limestones, shales, sandstones, we are naturally led to infer that this was due to movement in an opposite direction, viz. upheaval.

(2) There are three districts where the transition from limestone to shale and grit is abrupt and striking. The one is in South Wales, where a pebbly grit often rests directly on the top of the limestone. The second is in North Wales (Flintshire), where the grits thin out westward and allow Coal-measures with a layer of quartz-pebbles at the base to rest on the limestone in the Vale of Clwyd. The third is that of Derbyshire, where the summit of the limestone is marked by a kind of shell conglomerate, and directly succeeded by shales with a different fauna. These facts also suggest upheaval.

(3) Where the Millstone Grits are thickest, as in Derbyshire, Lancashire, and Yorkshire, the lowest of these grits is the coarsest, and its component grains are angular and little worn. From this area of thick grits there is a gradual diminution in the quantity and coarseness of the sand not only in every direction horizontally

(except eastward) but also vertically upward. Whether the grits thin eastward we do not know, for they are concealed from view. With regard to the upward sequence it was pointed out by the late Professor A. H. Green that the Millstone Grits are coarse-grained, massive, and persistent over large areas; that though sandstones still play an important part in the Lower Coal-measures they are not so coarse nor so thick as those below, while in the middle measures thick sandstones are rare, and when they do occur they are fine-grained and seldom extend as continuous beds for more than a few miles. This change in character, as well as the coming in of coal-seams, indicates a corresponding change in the physical conditions of the time.

(4) Although the succession in Devonshire is so different, yet there is a similar sharp contrast between the lower and middle Culm-measures, and in South Devon an actual break between them. Mr. Ussher remarks that there was an irregular shoaling of the sea after the formation of the Lower Culm, and is certain "that the Middle Culm sandstones were deposited in shallow water." [32]

I have shown elsewhere[33] that the facts connected with the Millstone Grit cannot be explained by merely assuming a cessation of the great subsidence; there must have been a reverse movement and an upheaval of the whole British region, while the character of the Upper Carboniferous of Russia shows that there was a corresponding subsidence of that region. The upward movement in the British area was not, however, of long duration, and must certainly have exhausted itself before the commencement of the lower Coal-measures, when subsidence again set in. The gradual overlap of one group of Coal-measures beyond the other over the surface of the central island proves that this island sank gradually till it reached a lower relative level than it occupied in the time of the Carboniferous limestones.

The upheaval which produced the great change probably acted in the following manner. It necessarily caused an extension of the land areas at the expense of the sea-spaces, and at the same time it reduced the depth of the seas which were left. The increased height of the land gave rise to an increase of the rainfall, an acceleration of all detritive processes, and imparted a greater velocity to the rivers and streams. Hence large quantities of land detritus would be swept into the shallowing seas till at length broad tracts of these seas were silted up and converted into marshy flats suitable for the growth of the Calamites, Lepidodendrons, and Ferns which are so abundant in the Coal-measures. Thus when subsidence again set in large areas of the sea had been converted into shallow-water lagoons and waterways surrounded by marshy land, and the amount

of detritus brought down from the land seems generally to have been sufficient to counterbalance the submergence and to fill up the space till it was again converted into marshy land.

With respect to the manner in which beds of coal were actually accumulated there is some difference of opinion, and it is doubtful if all coal-seams were formed in the same way. The view which has hitherto been most generally accepted is that the coal has resulted from the growth and decay of vegetation on the place where it is now found. This appears to be the most probable origin of many coal-seams which rest on beds of clay or shale that are penetrated by stigmaria rootlets. But there are cases where coal-seams rest directly on limestone or sandstone without any evidence of growth *in situ*, and a case has recently been described of a coal-seam passing gradually and horizontally into a carbonaceous dolomite.[34] In these and other instances the material of the coal appears to have been drifted by a current into still water and there deposited like other aqueous sediments.

In the modern world the nearest analogy to the conditions under which the Coal-measures were formed is probably to be found in the mangrove swamps which exist at the mouths of so many rivers within the tropics; in such swamps there is both growth *in situ* and transport by sluggish currents in close proximity to the sea.

A coal-seam, therefore, may be regarded as the final phase in the temporary silting up of a swampy district when a pause in subsidence allowed either of the actual growth of plants *in situ*, or of the formation of a quiet lagoon in which a thick layer of vegetable matter could be accumulated. On the other hand, the occurrence of a bed containing marine fossils indicates a time when renewed subsidence took place causing the waters of the still open outside sea to overflow the wide alluvial levels.

When we remember that what are now separate basins or coal-fields were in most cases connected with each other across the intervening anticlines, and further, that this development of Coal-measures is not peculiar to Britain, but seems to have been a contemporaneous formation over the greater part of Western and Central Europe, we must conclude that a vast region of alluvial land was produced during this epoch, the conterminous deltas in fact of the numerous rivers which drained the continents to the north, west, and south, just as Holland now is the conterminous delta of the Rhine, the Meuse, and other rivers.

Now the time necessary for the progress and consummation of all these natural operations must have been enormous, and yet the changes in physical geography must have been so slight and so slow throughout this great length of time that they did not materially

alter the relative positions of land and sea, or interrupt the process of swamp formation. This, then, is the peculiar and remarkable point in Carboniferous history which I desire to impress upon the reader's mind, that the latter half of it was a period of internal quiescence, a period in which terrestrial disturbances were at a minimum, and consequently when the surface agencies of change were able to continue their course of action to a greater extent than usual.

It is a well-known axiom in physical geology that if these surface agencies were to be allowed full play, and were not checked or balanced by terrestrial movement, every continent would gradually be reduced in height, and worn down to a level but little above that of the sea, while the surrounding waters would be choked and shallowed by the materials poured into them from the wasting land. It would appear, therefore, that the Carboniferous was a period when this theoretical result was more nearly approached in Western Europe than it ever has been before or since, when the land areas were gradually lowered by the combined action of detrition and depression, the area of high ground being continually diminished, but the area of low-lying, swampy ground at or about the sea-level being continually increased.

References

[1] See J. W. Salter in *Quart. Journ. Geol. Soc.* vol. xix. p. 476 (1863).

[2] See W. A. E. Ussher on "The British Culm-measures," *Proc. Som. Arch. and Nat. Hist. Soc.* vol. xxxviii. p. 111, and vol. xlvi. p. 1.

[3] G. J. Hinde and H. Fox, *Quart. Journ. Geol. Soc.* vol. li. p. 656 (1895).

[4] See a paper by Mr. H. A. Bemrose in *Proc. Geol. Assoc.* vol. xvi. p. 165.

[5] See paper on "Organic Origin of Chert," *Geol. Mag.* Dec. 3, vol. iv. p. 435.

[6] See *Quart. Journ. Geol. Soc.* vol. lvii. p. 347 (1901).

[7] See Tiddeman, *Congrès Géol. Internat. Compte-rendu for 1888*, p. 314, and J. E. Marr, *Quart. Journ. Geol. Soc.* vol. lv. p. 328.

[8] *Quart. Journ. Geol. Soc.* vol. xxx. p. 394.

[9] *Ibid.* vol. xl. p. 614 (1884).

[10] See *Geol. Mag.* Dec. 2, vol. ii. p. 543 (1875).

[11] *Ibid.* Dec. 3, vol. iv. p. 117.

[12] *Ibid.* Dec. 4, vol. v. p. 342 (1898).

[13] *Proc. Geol. Assoc.* vol. xv. p. 117 (1897).

[14] *Quart. Journ. Geol. Soc.* vol. xxxvi. p. 559 (1880).

[15] *Geol. Mag.* Dec. 4, vol. iii. pp. 155 and 222.

[16] The reader will find good accounts of the Carboniferous system of Ireland in Kinahan's *Geology of Ireland* (Kegan Paul and Company, 1878), in a paper by Professor Hull in *Quart. Journ. Geol. Soc.* vol. xxxiii. p. 616, and in the same author's *Coal-fields of Great Britain*.

[17] See Portlock's *Geology of Londonderry*, p. 564 (1843), and *Geol. Survey of Ireland*, explanations of sheets 19, 26, and 27 (1882 to 1884).

[18] Jukes's *Manual of Geology*, second edition (1872), p. 512.

[19] Jukes's *Manual of Geology*, second edition, p. 510, third edition, p. 588.
[20] See *Quart. Journ. Geol. Soc.* vol. xxxiii. p. 699, and *Trans. Roy. Dub. Soc.* 1880, p. 141.
[21] "Devonian Fauna of Southern England," *Palæontographical Society*, volumes for 1896 to 1898.
[22] Rutley, the "Rocks of Brent Tor," *Mem. Geol. Surv.*, and *Quart. Journ. Geol. Soc.* vol. xxxvi. p. 285.
[23] Described by Messrs. Gibson and W. Hind in *Quart. Journ. Geol. Soc.* vol. lv. p 548, and vol. lvii. p. 347.
[24] See *Ancient Volcanoes of Great Britain*, by Sir A. Geikie (pp. 397 and 400), to which the reader is referred for particulars of British Carboniferous volcanoes.
[25] The *Student's Handbook of Physical Geology*, second edition, p. 449 (Bell and Sons), 1892.
[26] The "Geology of the South Wales Coal-field," *Mem. Geol. Surv.*, Parts I. and II.
[27] The "British Culm-measures," *Proc. Som. Arch. and Nat. Hist. Soc.* vol. xxxviii. p. 111.
[28] See a paper by Mr. W. Gibson in *Quart. Journ. Geol. Soc.* vol. lvii. p. 261.
[29] See Professor Lapworth on "Geology of the Birmingham District," *Proc. Geol. Assoc.* vol. xv. p. 368.
[30] W. Gibson in *Quart. Journ. Geol. Soc.* vol. lvii. p. 251.
[31] *Mem. Geol. Surv. Ireland.* Explanation of Sheet 35.
[32] *Som. Arch. and Nat. Hist. Soc.* vol. xlvi. p. 51.
[33] *Building of the British Isles*, second edition (1892), p. 136.
[34] By A. Strahan in *Quart. Journ. Geol. Soc.* vol. lvii. p. 297.

CHAPTER XII

THE PERMIAN SYSTEM

THE **classification** of the rock-groups which intervene between the Carboniferous and the Jurassic systems has been the subject of much controversy. Formerly the whole of them were grouped together under the name of New Red Sandstone and classed as Mesozoic, but in 1841 and subsequent years Sir R. I. Murchison advocated their separation into two great divisions, and, relying solely on the Carboniferous affinities of the fossils in the lower division, he retained that part in the Palæozoic series, and regarded the upper division as the base of the Mesozoic series. At the same time he named the lower rocks *Permian*, from the ancient kingdom of Perm in Russia, while for the upper rocks the German name of *Trias* has been generally employed.

Although the name Permian has been adopted in England and Russia, it made its way very slowly in Germany, mainly because Murchison made mistakes in his grouping of the German rocks. In that country the strata, which are really of Permian age, fall into two strongly-contrasted divisions, and just as the overlying *Trias* was named from its consisting of three such groups, so the term *Dyas* was proposed by Marcou in 1859 from the duality of the underlying system. This name was adopted by Geinitz, and was for a time much used on the continent, but Professor Kayser and others have more recently preferred the older name as on the whole a better one.

Much difference of opinion has been expressed from time to time as to the relations of the Permian rocks with the Carboniferous on the one hand, and with the Trias on the other. In some areas there appears to be such a gradual transition from the Coal-measures upwards, that Permian strata have been called *Post-Carboniferous* or *Permo-Carboniferous*, while in other places

the Permian is clearly unconformable to the Carboniferous, and there is so much similarity between the red rocks of the Permian and those of the Trias that some authors have revived the idea of the New Red Sandstone under the title of a Poikilitic system (from the word ποικίλος, variegated).

The explanation of these doubts and difficulties seems to be that the Permian strata of Northern Europe were formed in a land-locked inland sea something like the Black Sea or the Caspian of the present day, and that this sea was inhabited by a dwarfed and modified remnant of the Carboniferous fauna. Further, that the period was in Europe one of considerable terrestrial disturbance, so that the continuity of deposition was broken, but not everywhere at the same time, while outside the region enclosing this inland sea there was a larger and more open sea occupying Southern Europe and large parts of Asia, where the evolution of life was in full progress and a varied fauna was developed.

While, therefore, the British geologist is specially interested in the Permian rocks of Britain, he must remember that they are part of an exceptional facies, and that for the normal marine development of the system he must look to Asia and Southern Europe. From this point of view such a term as Permo-Carboniferous seems to be unnecessary. It may be difficult in some regions to draw any hard-and-fast line between Carboniferous and Permian, but this difficulty occurs in the case of other systems, and it is better to class some of the passage beds as Carboniferous and the others as Permian even if the line of separation is an artificial one. The question which really requires an answer is this, Does the Permian series and the Permian fauna where fully developed, as in India, deserve to be ranked as a system, distinct from the Carboniferous on the one hand, and the Triassic on the other?

As we possess a marine type of Permian in Britain it will be convenient to describe the British rocks first and to recur to their foreign equivalents afterwards.

The typical Permian of Britain occurs in the north-east of England, and extends southward from the coast near Sunderland to Nottingham; the strata along this tract consist principally of dolomitic limestone and gray shaly marls. There is another Permian area in Cumberland, and small tracts occur in Ireland.

It has been stated on p. 261 that much of what has hitherto been regarded as Permian in the Midland counties really belongs to the Upper Carboniferous series, but there are certain breccias both there and in Devon which may be of Permian age.

Fossils of the Permian in Britain and Germany

As already mentioned, the fauna of the Permian strata found in Britain and Germany is merely a survival of the Carboniferous, and must not be regarded as the typical fauna of the Permian period, which will be briefly described on a later page.

In the two countries referred to the fossil assemblage is of a

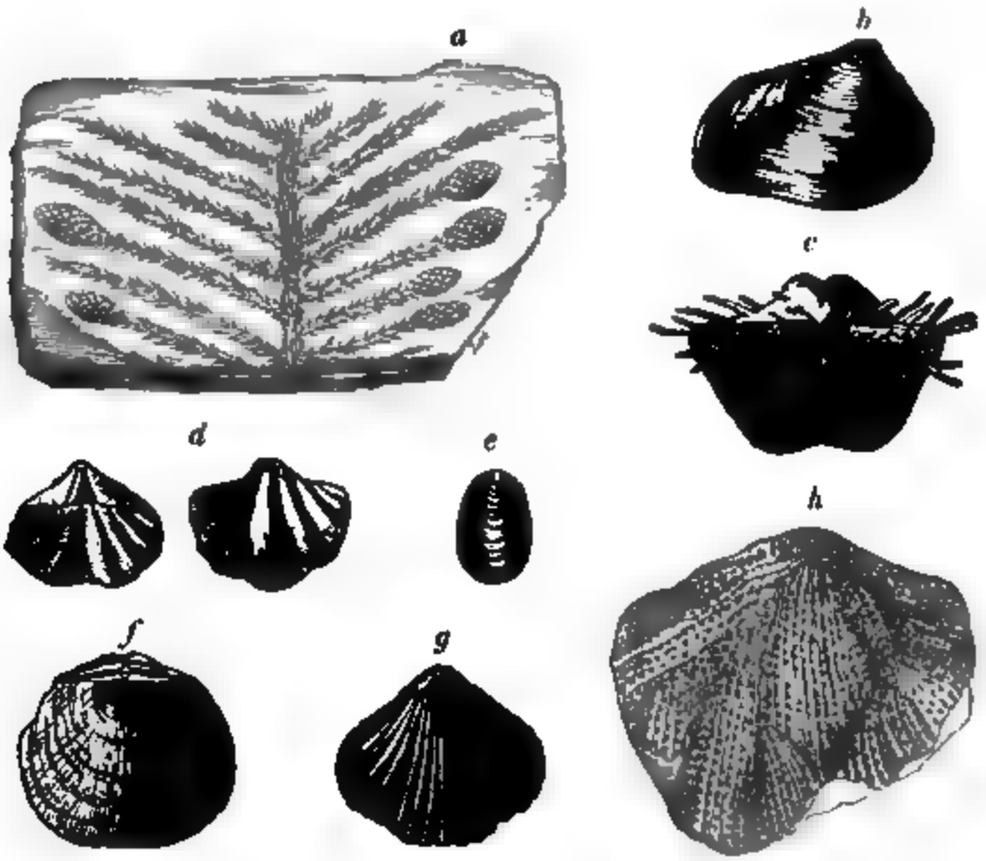

Fig. 90.—GROUP OF PERMIAN FOSSILS.

a. Walchia hypnoides.
b. Schizodus Schlotheimi.
c. Productus horridus.
d. Spirifer alatus.
e. Lingula Credneri.
f. Strophalosia lamellosa.
g. Camarophoria Schlotheimi.
h. Fenestella retiformis.

limited and uniform nature, resembling in this respect the fauna of modern inland seas. Of corals and echinoderms there are very few. Among Crustacea small Ostracods and Phyllopods occur, but of the ancient order of Trilobites there is no representative, though the genus *Phillipsia* still survived in Russia and North America. The Brachiopoda, Lamellibranchia, and Gastropoda are all referable to Carboniferous genera, but the species are few in number, and are mostly rather small, as if dwarfed by the con-

ditions under which they lived. On the other hand, conditions appear to have been favourable for Bryozoa, which are numerous and often large. Cephalopoda are rare, and are limited to a few species of *Temnocheilus* and *Orthoceras*.

Among Vertebrate animals, Fish are well represented, the principal genera being *Acrolepis*, *Amblypterus*, *Cœlacanthus*, *Palæoniscus*, *Platysomus*, *Acanthodes*, *Pygopterus*, *Rhabdolepis*, and *Pleuracanthus*.

Amphibia of the Labyrinthodont order have been found, and their footprints are not uncommon, *Archegosaurus*, *Branchiosaurus*,

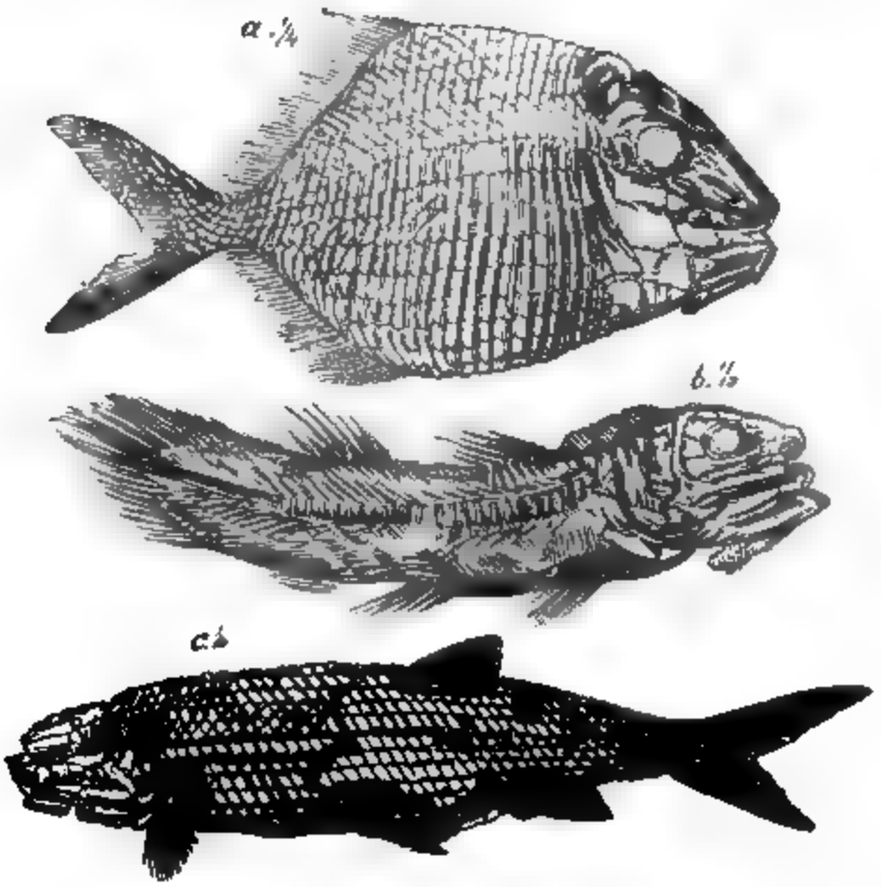

Fig. 91.—PERMIAN FISH.

a. Platysomus striatus. *b*. Cœlacanthus granulosus.
c. Palæoniscus comptus.

and *Lepidotosaurus* are the names of three, but many others have been obtained in Bohemia and described by Dr. A. Fritsch. Among these the small *Protriton* and the huge *Palæosiren* may be mentioned.

The Permian of Germany has also yielded the earliest known representatives of the Reptilia, belonging to the extinct order of Rhynchocephala. These include *Proterosaurus* and *Palæohatteria*, while *Parasaurus* and *Naosaurus* belong to a group, the members of which have only been found in the Permian and Trias, and

are remarkable as generalised types with characters that suggest an ancestral relationship to the Mammalia.[a]

The following are some of the most characteristic species of the English and German Permian :—

Plants.	(*Filices*): Neuropteris Huttoniana, Odontopteris obtusa, Callipteris conferta : (*Equisetaceæ*), Calamites gigas : (*Coniferæ*), Walchia piniformis, W. hypnoides, Ullmannia Bronni, U. lycopodioides.
Bryozoa.	Fenestella retiformis, Synocladia virgulacea.
Brachiopoda.	Camarophoria Schlotheimi, Strophalosia lamellosa, Productus horridus, Spirifer alatus, Lingula Credneri.
Lamellibranchia.	Pseudomonotis speluncaria, Pleurophorus costatus, Bakewellia antiqua, B. ceratophaga, Schizodus obscurus, S. Schlotheimi.
Gasteropoda.	Loxonema fasciatum, Natica minima, Pleurotomaria antrina, Turbo mancuniensis.
Cephalopoda.	Temnocheilus Frieslebeni.
Fish.	Platysomus striatus, Palæoniscus comptus, P. macropomus, Cœlacanthus granulosus, Acrolepis Sedgwickii, Rhabdolepis macropterus.
Amphibia.	Lepidotosaurus Duffii, Branchiosaurus amblystomus, Dasyceps Bucklandi.
Reptilia.	Proterosaurus Speneri.

Stratigraphy

1. *North-East of England*

Permian rocks occupy the coast-line of Northumberland and Durham from Tynemouth to Hartlepool, and their base can be followed inland from South Shields to Auckland and the valley of the Tees. Where the beds are fully exposed the succession is as follows :—

		Feet.
	Red marls and sandstones	50
Magnesian limestone.	Yellow concretionary limestone	200
	Brecciated limestone with fossils	150
	Compact limestone	200
	Brown calcareous shale ("Marl Slate")	3
	Friable yellow sand	from 0 to 96
		Up to 700

The yellow sands lie unconformably on the Coal-measures and fill up hollows in its surface, so that in some places, as near Cullercoats on the coast, they are nearly 100 feet deep, while occasionally prominences of the old floor cut them out altogether.

The Marl Slate, though seldom more than 3 feet thick, is important on account of the numerous fish-remains which it contains, and of which there is a fine collection in the Newcastle Museum.

[a] Other reptiles have been found in South Africa belonging to the order Anomodontia.

The highest part of the limestone consists mainly of concretions of crystalline dolomite, which have an internal radiating structure, and in parts these concretions are as large as cannon-balls.

Although the strike of the Permian beds is at first nearly in accordance with that of the underlying Coal-measures, yet they do not participate in the anticlinal flexures, which give an east and west strike to these measures in South Durham. Near the valley of the Tees the Permian oversteps the Coal-measures, and rests on the Millstone Grit; at the same time the greater part of it is overlapped by the Triassic sandstone, the width of the tract occupied by the Magnesian Limestone being gradually diminished, till between the valleys of the Tees and the Ouse only a narrow strip of it remains between the Trias and the Carboniferous rocks, and this is hidden by superficial deposits (see Map, p. 218).

Near Bedale in Yorkshire the overlap lessens again, and the Permian extends southward in a broader strip between the Carboniferous and the Trias as far as Nottingham, for a distance of nearly 90 miles. In Yorkshire, near Pontefract and elsewhere, the limestones are thinner, but the marl slates are thicker than in Durham, and sometimes rest on white and yellow sands, which in turn rest on an eroded surface of red marls and sandstones belonging to the upper Coal-measures (see p. 263). In South Yorkshire the succession may be summarised as follows: [1]—

	Feet.
Upper red marls	50
Upper (Brotherton) limestone	50 to 120
Middle red marls	30 to 50
Middle limestone, thick-bedded	150 to 200
Lower limestone	about 120
Blue limestones and shales	5 to 15
Quicksands and breccia	10 to 20
	From 430 to 570

Traced southward into Nottinghamshire, the Upper Limestone thins southward, and is at the same time overlapped by the Trias, so that the thickness of the Permian at its outcrop is very much diminished, being as follows:—

	Feet.
Middle marls and sandstones	20 to 30
Magnesian Limestone (lower)	60 to 70
Marl Slates	30 to 50

Southward near Kimberley the limestone passes into a yellow calcareous sandstone about 30 feet thick, resting on 15 to 20 feet of shaly marl, with a few feet of coarse breccia at the base.[2] This change and diminution in thickness is evidently an indication that we are in this direction approaching the southern shore of the

Permian sea. The breccia contains angular fragments of sandstone and shale derived from the Coal-measures on which it rests, together with pebbles of slate, quartz, and quartzite, and it is not unlikely that these were derived from a northerly prolongation of the Charnwood Forest rocks.

North of Nottingham the Triassic sandstones sweep southward across the Permian, and westward up the valley of the Trent, concealing all the underlying rocks.

We may here notice the results of several borings, which give us some information regarding the character of the formation in its eastward subterranean extension.

Near Middlesbrough in Yorkshire two borings were made, in 1862 and 1874 respectively, through the Trias, and into strata which appear to belong to the Upper Permian, but which include beds of gypsum and rock salt that are not found anywhere along the outcrop. The following is an abstract of the borings :—

		I.	II.
	Surface and glacial deposits	43	77
Trias	Triassic marls and sandstones	1163	1050
	Rock salt (and gypsum in II.)	100	134
Permian	Magnesian limestone with *Schizodus*	7	52
	Gray limestone	...	15
	Gypsum, rock salt, and marl	...	27
		1313	1355

Far to the south, and nearly due east of the southern end of the outcrop, another more complete and interesting section of the Permian was furnished by a boring between Scarle and Collingham near Newark. In the following account I follow Mr. W. H. Dalton, who had access to special information regarding this boring.[3]

		Feet.
	River gravel	21
	Lias and Rhætic	44
Trias, 1435 feet	Keuper marls and sandstones	893½
	Bunter sandstones and pebble beds	541½
Permian, 519 feet	Upper marls	118½
	Upper magnesian limestone	43½
	Marl and sandstone	150
	Middle magnesian limestone	68
	Sandstone	20
	Oolitic and shaly limestones	118
	Coarse grit and breccia	1
	Coal-measure shales	12
		2031

From this boring we learn that the Permian series maintains its thickness to the eastward beneath the Trias, and that the shore

of the Permian sea must have lain considerably to the south of Newark. We shall see in the sequel, however, that the magnesian limestones do not extend into Leicestershire.

2. *North-Western Counties*

Lancashire.—Crossing the great anticlinal flexure of the Pennine chain, we find beds which are referable to the Permian system near Stockport and Manchester, on the southern border of the Lancashire coal-field (see Map, p. 218).

Near Stockport they are separable into two groups: (1) a lower, consisting of soft bright red and variegated sandstones, estimated at some 1500 feet in thickness; (2) an upper, composed of red marls, with some beds of hard stone, 130 feet. The latter are only seen in faulted strips to the west of Stockport, being overlapped eastward by the Trias. The same series is found near Manchester, where the lower beds are sometimes called the Collyhurst sandstone; their thickness, however, is much less, varying from 375 feet on the east to only 20 and 12 on the west of Salford. The upper group consists of marls and limestones, with a maximum thickness of 250 feet, and these beds have yielded fossils of Magnesian Limestone types. More recently fossils have been obtained from these beds at Fallowfield, and the fossils include *Schizodus Schlotheimi*, *Pleurophorus costatus*, *Bakewellia antiqua*, *Aucella Hausmanni*, *Natica minima*, *Turbo helicinus*, and *Rissoa Gibsoni*.[1]

At Bispham near Ormskirk an interesting section is exposed in the sides of a dell called Skillaw Clough; this has a still greater resemblance to the north-eastern type, and is as follows:—

	Feet.
Yellow magnesian limestone	6
Red and purple shales	30
Soft red and brown sandstones	35

Still farther north several small outlying patches of Permian have been found, one east of Preston, another near Clitheroe, where it lies on Carboniferous limestone, and a third rather larger area in the centre of the Burton coal-field; these occurrences show the beds to be completely unconformable to the Carboniferous rocks, just as on the eastern side of the Pennine anticline.

Cumberland.—No other remnants of the Permian have been discovered till we reach the broad vale of Eden in Cumberland, where rocks of Permian age appear in much greater force, and extend from Kirby Stephen in Westmoreland, by Appleby and Penrith, to within about three miles of Carlisle, where it is faulted

down below the Triassic (St. Bees) sandstone. This tract is bounded on the east by the great Pennine fault, and on the west also it is faulted for some distance against the Carboniferous limestone. Everywhere the Permian rests unconformably on the Carboniferous, and attains a much greater thickness than in any other district. Red sandstones and breccia, consisting of limestone pebbles embedded in a sandy matrix (locally called *brockrams*), are the most prominent members of the series.

At Hilton Beck, near Appleby, the following section was measured by Mr. Goodchild :—

	Feet.
Magnesian limestone	25
Hilton shales with plant-remains	40
Breccias and red sandstones	150
Current-bedded red sandstone	300
Lower breccias (brockrams) seen for	100
	615

The limestone has not yielded any fossils, but the shales

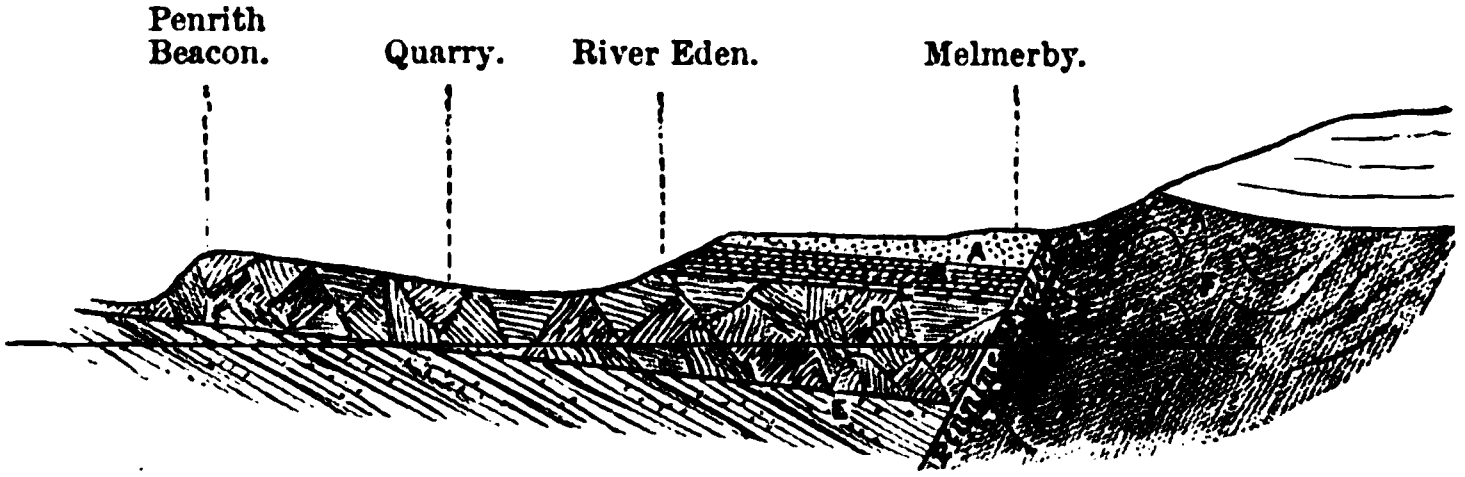

Fig. 92.—SECTION THROUGH THE PERMIAN BEDS NEAR PENRITH (after Prof. Harkness).

A. Red sandstone.
B. Red shale.
C. Magnesian limestone } Permian.
D. Penrith sandstone }
E. Carboniferous rocks.
F. Ordovician rocks.

below contain *Ullmannia selaginoides*, *Cardiocarpus triangularis*, *Alethopteris Goepperti*, *Sphenopteris Naumanni*, and *Odontopteris*. The shales are interbedded with sandstones, and form a band which expands in places to 150 feet.

The brockrams are thickest to the south-east round Kirkby Stephen, and thin out lenticularly in the red sandstones to the north-west, so that at and north of Penrith the whole formation is represented by the bright red false-bedded sandstone which is known as the Penrith sandstone, and has a maximum thickness of 1500 feet.

Other small patches of Permian occur in the extreme west of the county near Whitehaven. The cliffs between that town and St. Bees Head show the following succession of beds :—

		Feet.
Trias	Red sandstones of St. Bees	600
	Red and green marls with gypsum	30
Permian	Magnesian limestone with casts of fossils	11
	Breccia of limestone fragments	3
Carboniferous sandstone of a purplish gray.		

The breccia rests on an eroded surface of the purple sandstone, which was formerly regarded as Permian, but is now known to be Carboniferous. Red sandstones of the Penrith type occur inland near Egremont and Arlecdon, but do not come into the coast section. Casts of *Schizodus* and *Bakewellia* can be recognised in the limestone.

It should be mentioned that the Permian of Cumberland is everywhere overlain by a set of red shales and marls with beds of gypsum, and by some these are classed as Permian; but Mr. Goodchild has pointed out that they rest sometimes on the limestone, sometimes on the Hilton shales, and sometimes on Penrith sandstones, so that there is a decided unconformity, and the marls should be regarded as the base of the Trias.

3. *The Midland Counties*

No beds comparable with the magnesian limestone, nor any beds containing undoubted Permian fossils, have been found to the south of Nottingham on the eastern side, or of Stockport on the western. There is, however, a considerable thickness of red rocks in the Midland counties between the productive Coal-measures and the Triassic sandstones; and some of these rocks are probably of Permian age; but, as already mentioned (see p. 261), the lowest part of this red series is now considered to be of Carboniferous age, and it is somewhat doubtful how much of the rest can properly be separated from the Carboniferous on the one hand, and from the Trias on the other.

To explain this uncertainty we must refer to the classification proposed in 1869 by Professor Hull,[5] who divided the series of strata which were then referred to the Permian into three groups or stages, thus :—

Upper	Red and purple sandstones and marls.
Middle	Breccia of felspathic and other rocks.
	Sandstones and marls with bands of calcareous conglomerate.
Lower	Red and purple sandstones and marls.

It is now admitted that the lower of these three stages must be classed with the Coal-measures, and it has been described on a previous page under the name of the Keele Beds.

The combined thickness of the remaining middle and upper groups is generally less than that of the lower group, and varies from 500 to perhaps 800 feet. These beds have recently been investigated by Mr. W. W. King, who considers the breccia to be more closely connected with the upper than with the middle group. He has also made a special study of the pebbles in the conglomerates, and shows them to be a varied assortment derived from all the older rocks of the Midland area, including the Carboniferous limestone and the Coal-measure sandstones, and there are even pebbles of the so-called "Lower Permian" sandstones.[6]

It would appear, therefore, that the conglomerate group must be unconformable to the Carboniferous system as a whole, and that if any part of the Midland succession can be regarded as Permian it is this central group with its conglomerates. The relations of the higher beds are rather more doubtful, because they have a wider extension and their lithological characteristics are somewhat different. On the other hand they appear to follow in conformable succession, while it is believed that the lowest member of the Trias rests unconformably upon all the underlying strata, including the breccia and the highest marls. I therefore follow Professor Groom in retaining these beds in the Permian series.

Consequently the Midland Permian may be regarded as consisting of three members, but as it would obviously lead to much confusion if these subdivisions were termed Lower, Middle, and Upper, it will be best for the present to describe them under the following names :—

	Feet.
3. Upper (or Enville) marls	100 to 150
2. The Trappoid Breccia	50 to 450
1. The Conglomerate group	200 to 330
Total from	500 to 800

The thicknesses given are those found in the typical districts of Shropshire and South Stafford. When followed southward the conglomerate group thins out, and the marls are overstepped by the Trias, only small patches of the breccia being seen at intervals below the latter.

This Permian series follows the eastern border of the Coal-measures through Shropshire and Worcester, passing southward on to the Silurian rocks of the Abberley and Malvern Hills. To the eastward it borders the southern half of the South Staffordshire coal-field, but does not extend to its northern extremity. How far it extends beneath the Trias east of this coal-field, and

whether any of it reappears near Coventry are points that remain for decision, but it is known that most of the area coloured Permian by the Geological Survey on the western side of the Warwickshire coal-field is composed of "Lower Permian" beds, which are now classed as Upper Coal-measures.

The Midland Permian, as above restricted, attains its fullest development in Shropshire, and is well exposed in the neighbourhood of Enville on the Staffordshire border (see Fig. 93). Another typical district is that of the Clent Hills in Staffordshire, where the trappoid breccia attains its greatest thickness, but the upper marls are not seen, being presumably concealed by the overstep of the Bunter pebble beds (Trias).

The following account refers more particularly to the Enville district, and has been compiled from Mr. King's paper.

The Conglomerate Group.—This consists of soft red sandstones and red marls with three interbedded bands of calcareous sandstone and conglomerate, the latter consisting of various pebbles embedded in a sandy matrix, which is cemented by carbonate of lime. The second of these bands is the thickest, being sometimes a massive conglomerate 75 feet thick, and sometimes including lenticular beds of red sandstone with a total thickness of 150 feet. Both conglomerates and sandstones thicken to the north-west and become thinner to the south-west. In the Clent Hills this group is represented by red marls with three bands of sandstone and compact limestone or cornstone, without any conglomerate, but containing small fragments of the older rocks.

The nature of the pebbles varies considerably in different parts of the district. Thus in Shropshire about half the pebbles consist of dolomitic Silurian limestone, like that which occurs in the Abberley Hills, the other half consisting largely of Carboniferous limestone and sandstone. In Staffordshire, especially near Baggeridge on the west, and near Barr on the east side of the coal-field, the majority of the pebbles (60 per cent) are of Carboniferous limestone, most of the remainder consisting of Wenlock limestone. It is thus a remarkable fact that these conglomerates are essentially limestone conglomerates, but contain the débris of various rocks down to and including the Woolhope limestone.

The Trappoid Breccia was so called because it is largely made up of angular blocks of the compact felspathic lavas and tuffs, which were formerly known as "traps." They are really rhyolites, hornstones, felspathic tuffs, grits, and agglomerates, and have evidently been derived from Pre-Cambrian rocks like those which are known to occur in the Lickey Hills, at Barnt Green near Birmingham, and at Nuneaton. With these are associated many

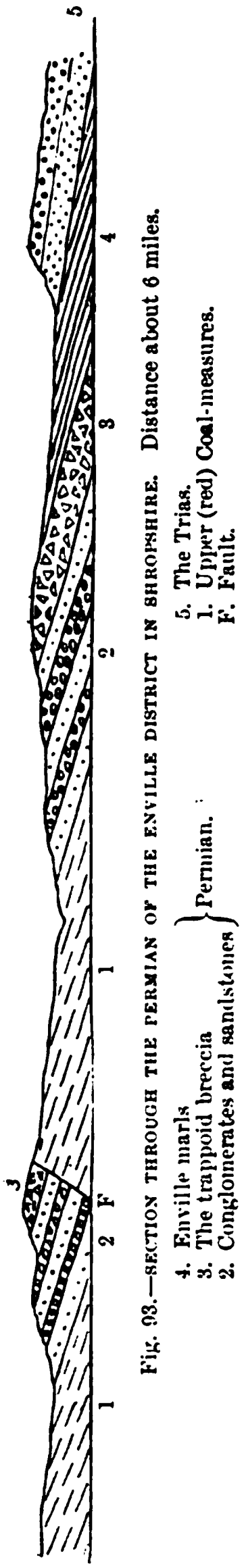

Fig. 93.—SECTION THROUGH THE PERMIAN OF THE ENVILLE DISTRICT IN SHROPSHIRE. Distance about 6 miles.

5. The Trias.
1. Upper (red) Coal-measures.
F. Fault.

Permian.
4. Enville marls
3. The trappoid breccia
2. Conglomerates and sandstones

fragments of Llandovery sandstone and a few of Woolhope limestone. Mr. King remarks on the contrast thus presented by the contents of this breccia with those of the conglomerates below, and points out that "the presence of the rocks down to the Woolhope in the limestone conglomerates, and of the rocks at and below the Woolhope [horizon] in the Upper Permian trappoid breccias, could be explained easily if the area which furnished the material to these Permian limestone conglomerates had been eroded down as a whole through the Carboniferous to the Woolhope limestone during Middle Permian time, while in the succeeding trappoid breccia period subäerial denudation cut through the Woolhope limestone and Llandovery sandstone deep down into the Archæan series" (*op. cit.* p. 126).

Another remarkable fact connected with this breccia is that many of the blocks are very large, and that some of them are scratched or striated, the striations resembling those of glaciated stones, so that Sir A. Ramsay was led to infer the existence of glaciers and glacial moraines to account for them. This view, however, has not been sustained, and the striations are now attributed to the grinding of rock-fragments against one another during the many subsequent earth-movements which they have experienced.

This breccia can be traced southward through Worcestershire, where it is often called the Haffield breccia, from its occurrence on Haffield Hill near Great Malvern. This is its most southerly outlier, but others occur on the Abberley Hills, resting on Silurian and Old Red Sandstone.

The Enville Marls are only found in Shropshire, and are not seen farther south than Enville, though they doubtless extend much farther southward beneath the Trias. They include a band of breccia which near Enville is 50 feet thick, but thins out to the north-west, while the thickness of marl increases in that

direction. It is clear, therefore, that the materials of this breccia, as of the main mass, came from the south and south-east.

4. *Leicestershire*

In Leicestershire there are a few small but interesting deposits of Permian age, which have been carefully studied and described by Dr. H. T. Brown and Professor Bonney.[7] They consist of gray breccias, gray sandstones, and red marls, not more than 60 feet thick in Leicester, but as much as 200 at Polesworth in North Warwick. The breccias thicken to the south and the marls to the north, and their thickness may originally have been greater, as they are overlain unconformably by the Trias.

The pebbles in the breccias consist of the following kinds of rocks :—

(1) The larger number (about 60 per cent) are felspathic grits or quartzites, derived from the Cambrian quartzites, but differing slightly from those exposed at Hartshill.

(2) Gritty slates from the same series, averaging 17 per cent.

(3) Flinty slates and argillites, possibly from the Charnwood series.

(4) Volcanic rocks, some being felsites and andesites from the pre-Cambrian (Caldecote) series, some of a rock which may have come from Charnwood, and Diorites like those in the Cambrian near Nuneaton.

(5) Fragments of Carboniferous grits, clay, ironstones, and hæmatite ; these are common in some places, but pebbles of Carboniferous limestone are rare, except at Polesworth.

In most of the exposed breccias over 80 per cent of the fragments come from the Cambrian quartzite series, and Dr. Brown shows that they have probably been derived from a buried ridge of these rocks which underlies Market Bosworth and runs parallel to the well-known Hartshill ridge. This buried ridge appears to be a faulted anticline, and so exact is the parallelism between these ridges and the principal faults of the Leicestershire coal-field that they may safely be attributed to the same period of earth-movement. These faults are known to be post-Carboniferous, and the undisturbed way in which the breccias lie, bridging over the faults, makes it very probable that they are of Permian age.

5. *Devonshire*

The only other area in England where Permian rocks occur is in Devonshire (see map, Fig. 56.) Here, as in the Midlands, a set

of sandstones, breccias, and marls underlie the Trias and rest unconformably upon all the older rocks; and though no fossils have been found in them, and though there is no great break between them and the Trias, yet they are now generally believed to be of Permian age. This view has been confirmed by Herr von Reinach, who remarks upon the close similarity of the Devon breccias to those of the German "Rothliegende" in the Hunsruck district between Trèves and Bingen.[8] The examination of the Devon and Somerset area by Mr. Ussher has resulted in the establishment of the following succession:—

	Feet.
Red marls with occasional sandstones (? Permian) .	about 500
Red sandstones	250 to 400
Red conglomerate and breccia	900 to 1100
Dark red Watcombe clays (local)	100 to 150
	Maximum about 2000

The Watcombe clays occupy some little space north of Torquay by Watcombe, Barton, and Daccombe, and they reappear between Teignmouth and Bishopsteignton. They consist of fine dark red clay which has long been used for the manufacture of terra-cotta ware, and it is also extensively dug for the making of tiles and hard bricks. The deposit seems to fill a broad hollow in the Palæozoic rocks, for it is overlapped by the breccias both to the south and the west.

The overlying breccias consist in the lower part of conglomerate and breccia, in which fragments of Devonian limestone are abundant. These beds are well exposed in the fine cliffs between Babbicombe and the estuary of the Teign, and their thickness is estimated at from 400 to 500 feet, but the frequent faults make the estimate uncertain. The higher breccias differ in containing a larger proportion of derived volcanic rocks, chiefly of a peculiar red quartz-porphyry, and some of the boulders are of large size. This portion has a thickness of from 500 to 600 feet, so that the total thickness of breccia is about 1000. These breccias stretch northward beneath the Haldon Hills, but the material becomes much less coarse in that direction; they send a long tongue westward along the Crediton valley and pass northward by Tiverton into Somerset, but become greatly diminished in thickness.

Near Dawlish the breccias graduate upward into sandstones which pass northward to Exeter, and these are succeeded by red marls with lenticular beds of sandstone, which seem to be an upward continuation of the series. If so, they ought to approach the horizon of the magnesian limestone, but no fossils have yet been found in them, and they may be of Triassic age.

6. *Ireland*

Rocks of Permian age are only found at two or three places in the north-east of Ireland, and they are similar to those in Cumberland, including representatives of both the arenaceous and calcareous portions of the series.

Magnesian limestone has been found at two localities: one at Tullyconnell, near Ardtrea, County Tyrone; the other at Cultra, on the southern shore of Belfast Lough, where they rest on red marls, and are faulted against Carboniferous rocks. Shells of *Schizodus*, *Bakewellia*, etc., have been found in them, proving their identity with the Durham limestones.

Shore-beds of Permian age have been identified by Professor Hull as occurring beneath the city of Armagh, the exposure at the Armagh marble quarries being as follows:—

3. Boulder beds, resting on conglomerate
2. Limestone breccia } 20 feet.
1. Carboniferous limestone.

The rocks here are of a deep red colour, rudely stratified, and the breccia at the base consists of limestone fragments in a matrix of compacted sand, like the Brockram of Cumberland. The blocks in the overlying boulder bed are of all sizes up to two feet in diameter, and consist of purple grits and felspathic sandstones derived from the Silurian and Old Red Sandstone districts to the north or west.

Permian Volcanic Rocks

If all the Scottish New Red is referable to the Trias (see p. 319), Devonshire is the only British area where contemporaneous lavas occur in Permian strata.

Extensive sheets of lava are associated with the Permian breccias of Devon, and the recent survey by Mr. Ussher shows that they occur in three localities, one west of Exeter, a second extending about twenty miles from Kellerton towards Crediton, and a third near Tiverton. The sheets of lava are of no great thickness, but are interbedded with agglomerates and ashy breccias; some are basalts and others are andesites, and they include slaggy, amygdaloidal, and pumiceous varieties.

The Permian of Europe and Asia

Rocks which are more or less similar to the British Permians have been found in Germany, Bohemia, Bavaria, Poland, and Russia; while a different facies occurs in Eastern Russia, Central

Asia, India, Carinthia, and Sicily. It will suffice to give here brief notices of the beds in Germany, Russia, and India.

Germany.—The typical Permian or Dyassic series of Germany is found in the Thuringerwald and on the flanks of the Hartz Mountains. Here it consists of two principal members: (1) the *Rothe-liegende*, a group of red sandstones and conglomerates resting unconformably on the Coal-measures, and varying greatly in thickness; (2) the *Zechstein*, a magnesian limestone with a thin band of black shale at the base, called *Kupfer-schiefer* (copper-slate), which is the exact analogue of our Marl-slate. The lower part of the Zechstein is a massive thick-bedded limestone, the upper part consists of red shaly clays with beds of gypsum and of thin-bedded limestone (*Platten-dolomit*). Its upper surface is eroded and covered by soft shaly sandstones locally termed the Bunter.

It is on account of the persistent development of these two groups in Northern and Central Germany that the system has been termed the Dyas. But when this Dyas is traced southward into Bavaria and Bohemia, the calcareous members die out, while the arenaceous members increase in thickness, till the whole series consists of sandstone and conglomerate with only thin local beds of limestone or calcareous breccia. This lateral change of sedimentary type is analogous to that which takes place in England, and in both countries the upper part of the arenaceous group may be correlative with the upper part of the calcareous group.

Russia.—The Permian rocks seem to have extended continuously eastward from Germany through Russia to the Ural Mountains, on the flanks of which they are largely developed, and it was from the ancient kingdom of Permia, which included the modern provinces of Perm, Kasan, Orenburg, etc., that Sir R. I. Murchison gave these rocks the name of Permian. Here they form a thick alternating series of sandstones, marls, limestones, and red clays, which lie almost horizontally and extend over many thousand square miles. Some of the beds contain Zechstein fossils, but these alternate with plant-bearing beds.

Farther east, however, on the western slopes of the Ural Mountains, the lower beds become marine and have a special facies with a fauna which is transitional between the Carboniferous and the Permian. This was described by Karpinsky in 1874 as the Artinskian stage (*Artinskische étage*); its fauna includes many brachiopods of Carboniferous species, such as *Productus cora*, *Spirifer lineatus*, but these are associated with Ammonoid Cephalopoda referable to the Indian genera *Medlicottia*, *Thalassoceras*, and others. The general succession is given on p. 293.

India.—In the northern part of India, and especially in the

hills known as the Salt Range, there is a complete passage from the marine Upper Carboniferous into rocks of Triassic age. The whole series is marine, and has been termed by some writers "Permo-Carboniferous"; but if a Permian system is recognised at all, this Indian series should be regarded as one type of its normal marine development. It consists mainly of limestones in which species of *Productus* are so abundant that they were called "the Productus limestones" by Waagen. His "Lower Productus limestone," however, occurs in the Speckled sandstone series which is now regarded as Upper Carboniferous, so that it is the Middle and Upper Productus limestones which form the Permian series. Waagen's subdivisions and their correlatives in Russia and Germany are given below.

Germany.	E. Russia.	India.	
Clays, gypsum, and Platten-dolomite	Red clays with beds of sandstone and limestone . . .	Top beds Cephalopoda beds	Upper Productus limestone.
Middle Zechstein	Marls and sands with *Productus cancrini*, etc. . . .	Middle beds Lower beds	
Lower Zechstein and Kupferschiefer	Dolomites, marls, and sands with marine fossils (Artinskian)	Upper beds Middle beds	Middle Productus limestone.
Rothliegende		Lower beds	

The fauna of the Lower Permian of India, *i.e.* the Middle Productus limestone, has many species in common with the Fusulina limestone of Russia, but along with Carboniferous brachiopods are also Permian species such as *Strophalosia excavata* and *Camarophoria humbletonensis*, and also some peculiar gigantic Thecidæ (*Lyttonia* and *Oldhamina*) and the Permian Bryozoon *Polypora biarmica*. In the upper division are Ammonoids of the genera *Medlicottia*, *Popanoceras*, *Arcestes*, and others, with many bivalves of the genera *Myophoria*, *Lucina*, and *Lima*, which are Mesozoic genera.

Physical and Geographical Conditions

In Chapter VI. the Carboniferous period was described as one of quiescence, during which the forces of terrestrial disturbance were in abeyance; but as a calm often precedes a storm in the atmosphere, and as a great stillness often forebodes an earthquake, so in the earth's history a period of quiet deposition and rock-making has often been followed by a period of disruption and rock-destruction. Certain it is that the calm of Carboniferous times was followed by an epoch of great disturbance in the

European and Atlantic areas, causing movements which produced very great geographical changes in the northern hemisphere.

The unconformity which exists in some localities between the upper and the older Coal-measures shows that some disturbances and flexuring took place before the close of the Carboniferous period, but the stratigraphical relations of the Permian to the Carboniferous series as a whole make it clear that much more forcible movements took place after the deposition of the Coal-measures. From the lie of the beds in the north of England it is evident that the east and west axes of flexure were produced in the interval, but it is not quite certain that the north and south axis of the Pennine Range was pre-Permian. There are good reasons, however, for thinking that its uplift began at this time, and that the Magnesian Limestone never spread completely over the whole length of the Pennine hills ;[9] at the same time it is probable that the western lake or inland sea was not entirely isolated from the eastern and larger sea.

It is quite possible that the north-western area of deposit was continuous with that of the western Midlands, and it would appear that this latter area was bounded on the south-east by a range of hills which consisted mainly of Cambrian and pre-Cambrian rocks. The reasons for assuming the existence of such a range have been given on p. 289 ; they have been termed the "Mercian Highlands," and their worn-down stumps must now be concealed beneath the Neozoic rocks. The general direction of this range of hills is described by Professor Lapworth as "crossing the Midlands along a north-east and south-west line from Charnwood through the Lickey Hills towards the Abberley and Malvern Ranges."

It seems probable, therefore, that the Devon and Somerset area was entirely separated from the more northern basins, and as the east and west axes of Brittany appear to be part of another pre-Permian upheaval, this south-western basin may have been an isolated lake, and possibly one of fresh water supplied by many streams descending from the high land to the west and south of it.

Professor Suess has pointed out that several important old mountain ranges date from the epoch of change from Carboniferous to Permian conditions. That of which Brittany was a part he calls the *Armorican*, and thinks it extended from Southern Ireland to the central plateau of France ; another, the *Iberian*, he traces from Galicia and Northern Portugal to the Guadalquiver in Southern Spain ; a third is the *Hercynian* range of the Hartz Mountains in Germany, and a fourth the *Variscian*, running from Central France to the north side of the Carpathians.

By these uplifts the open Mediterranean sea of the Carboniferous period in Europe was converted into a large inland sea, like the

Caspian of the present day, surrounded by a rocky and hilly continent, on which grew trees and plants of various kinds. Many of these plants are closely allied to those of the Carboniferous, but species belonging to the Yew and Fir tribes, which flourish on dry ground, preponderate over the reeds, ferns, and gigantic lycopodia which flourished in the Coal-measure swamps.

The western part of this inland sea stretched across the centre of what is now the North Sea, and covered a considerable part of Northern England, the Pennine hills being either a chain of islands or a double peninsula with intervening straits, by which the waters of the North European sea communicated with a western salt-lake covering the north-west of England and parts of Eastern Ireland. Until recently some red sandstones in the south of Scotland were referred to the Permian, but these are now regarded as Trias, and the probability is that a large area of land stretched continuously from the north of Ireland across Scotland and the northern part of the North Sea, and across Scandinavia into Russia.

The slopes which bordered the great inland sea and its subsidiary lakes seem in many places to have been very steep, for it is only on such slopes that the coarse breccias and brockrams, which are so prevalent both in England and Germany, could have been accumulated. The size and angularity of the blocks in them show that the materials have not travelled far, but are such as are formed at the foot of many mountain ranges at the present day.

In those parts of the sea which were more distant from high land limestones were formed, and their magnesian character suggests that they were partly of the nature of chemical precipitates. Finally, toward the close of the period a farther upheaval took place, the seas were still more contracted and were partially desiccated, so that the water became more saline, a process which resulted in the formation of thick deposits of rock salt and gypsum.

References

[1] See E. Wilson on "Permian Formation," *Midland Nat.*, vol. iv.

[2] For details consult the "Geology of the Country round Nottingham," *Geol. Survey Memoir*, by W. T. Aveline, p. 12.

[3] See E. Wilson in *Quart. Journ. Geol. Soc.* vol. xxxv. p. 813, and "Geology of the Country around Lincoln," *Mem. Geol. Survey*, 1888, pp. 3 and 194.

[4] *Trans. Manch. Geol. Soc.* vol. xxi. p. 13.

[5] The "Triassic and Permian Rocks of the Midlands," *Mem. Geol. Survey*, 1869.

[6] See *Quart. Journ. Geol. Soc.* vol. lv. p. 97 (1899).

[7] See *Quart. Journ. Geol. Soc.*, vol. xlv. p. 1, and the *Midland Naturalist*, vol. xv. 1892.

[8] See a note by Mr. W. A. E. Ussher in *Geol. Mag.* 3rd Dec. vol. ix. p. 247.

[9] See the author's *Building of the British Isles*, second edition, p. 161.

CHAPTER XIII

THE TRIASSIC SYSTEM

WITH the close of the Permian period the last remnants of Palæozoic life became extinct in the British area, and when after a long continental period the western and northern parts of Europe were again submerged beneath the sea, the waters were tenanted by a very different set of generic forms. The Palæozoic groups of Cystid and Blastoid Echinoderms, Rugose Corals, Eurypterids, Trilobites, Goniatites, and Orthoceratidæ are no longer represented, their place being taken by the Euechinoidea, Aporose Corals, Siphonate Gasteropods, and Cephalopods of the Ammonite and Belemnite type; many orders of Reptiles appear for the first time, and the earliest Mammal yet known occurs in the upper beds of the Trias.

Even where a continuous series of marine deposits bridges over the gap in the history of marine life which exists in Northern Europe we find that the above remarks are still practically true, for the only exception is the existence of a single species of *Orthoceras* in the Trias of the Alps. For reasons which cannot yet be fully explained the Triassic period seems to have been one of rapid organic change and development, and in no class is this more beautifully illustrated than in that of the Cephalopoda, the Alpine Trias presenting us with a remarkable assemblage of genera which practically connect the Palæozoic Clymenias and Goniatites with the Ammonites, which are so characteristic of the Mesozoic periods.

The British Trias belongs to the North European type, which is most completely developed in Germany, and has there been divided into three great groups, with the following names:—

3. Keuper (red marls and sandstones).
2. Muschelkalk (marine limestones).
1. Bunter (red marls and sandstones).

In Britain there is no representative of the Muschelkalk, but only of the Bunter and Keuper. The British and German strata,

being the deposits of inland seas and salt lakes, comparable with the Caspian Sea of the present day, cannot be regarded as the typical deposits of the period. For the normal marine facies of the Trias we must go to the Alps, and the student cannot understand the true relations of the Triassic system to those which precede and follow it until he has learnt something about the important marine facies of the formation which exists in the Tyrol and extends throughout Southern Europe.

Moreover, this marine facies has a wide extension over other parts of the world; it spreads through Southern Europe from Spain to Hungary and the Balkans, it is found in Turkestan, Central Asia, and the Himalayas, and a similar marine Triassic system occurs in Siberia, Japan, North America, and again southward in Columbia, Peru, New Zealand, and Australia. In South Africa, in South India, and in Argentina red sandstones with reptilian remains are found, and these regions seem to have formed part of other Triassic continents. In this volume, however, it is only possible to give a brief account of the Alpine Trias.

1. The Trias of the Alpine Region

The Marine Fauna.—The fauna of the Alpine and Tyrolian Trias presents us with an interesting mixture of Palæozoic and Neozoic forms of life, though the former are in a decided minority, the proportion of species belonging to genera which are essentially Palæozoic being stated as only one-tenth of the total number of species composing the fauna.

The Cephalopoda are a remarkable assemblage. A single species of *Orthoceras* with some of *Temnocheilus* and *Pleuronautilus* connect it with Palæozoic faunas, while the genus *Nautilus* (as now restricted) makes its first appearance. The Ammonoidea, however, are the dominant forms, and include many genera with nearly simple lobes, such as *Ceratites*, *Lobites*, *Tropites*, *Arcestes*, *Cladiscites*, and *Pinacoceras*, as well as genera with phylliform lobes, such as *Trachyceras*, *Ptychites*, *Phylloceras*, and *Megaphyllites*. There are also precursors of the Belemnitidæ in *Aulacoceras* and *Atractites*.

Gastropoda are abundant, and include representatives of the Palæozoic genera *Murchisonia*, *Loxonema*, *Naticopsis*, and *Euomphalus*, with the Neozoic types of *Trochus*, *Turritella*, *Scalaria*, *Cerithium*, and *Pseudomelania*, as well as peculiar forms which have been named *Naticella*, *Chilocyclus*, and *Ptychostoma*.

Of Lamellibranchs *Posidonomya*, *Megalodon*, and *Myophoria* (which is probably inseparable from *Schizodus*) connect the fauna with Palæozoic life, while certain genera are specially Triassic,

such as *Halobia* (*Daonella*), *Monotis*, *Cassianella*, *Trigonodus*, and

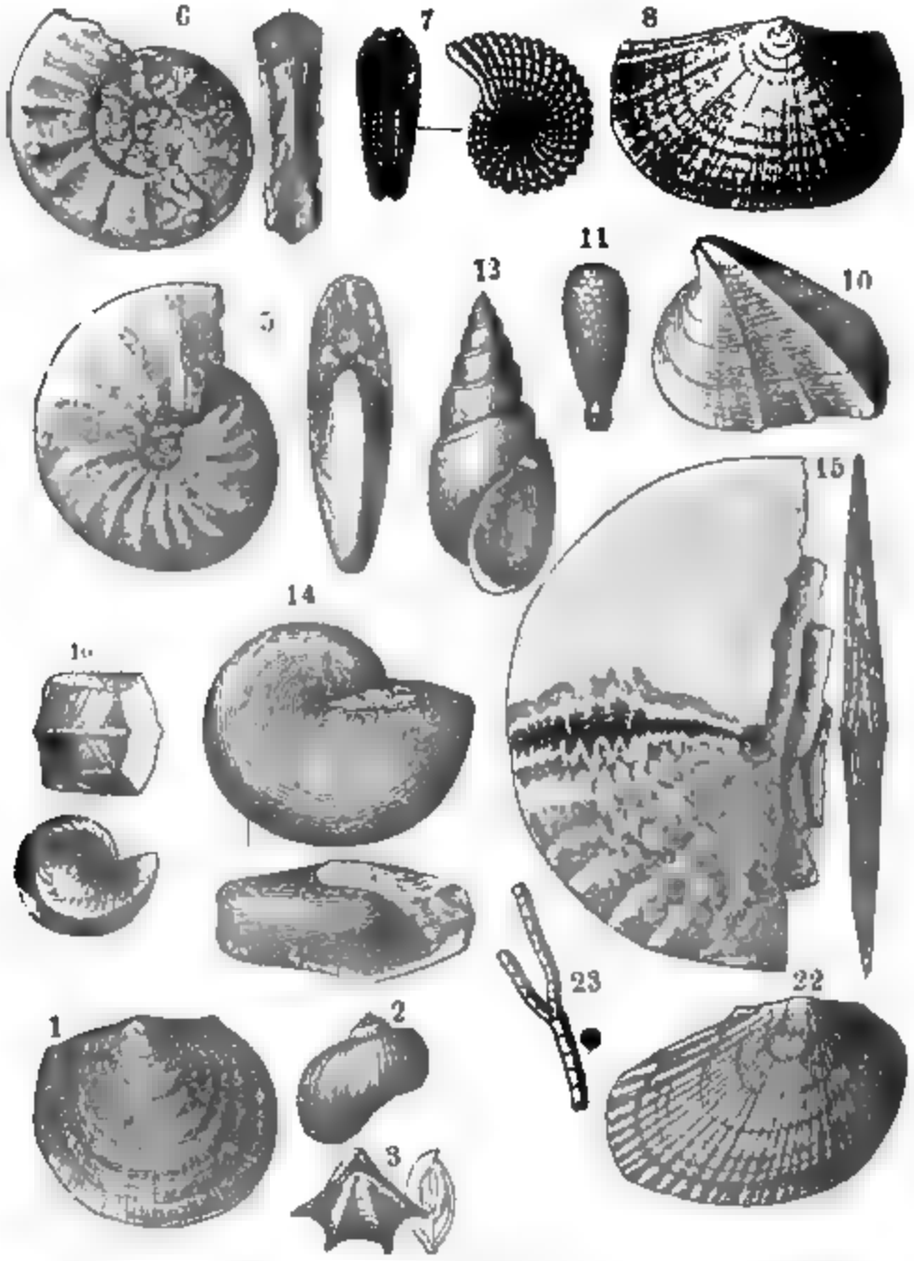

Fig. 94.—GROUP OF FOSSILS FROM THE ALPINE TRIAS.

1. Posidonomya Clarai.
2. Naticella costata.
3. Pleigem trigonella.
5. Ptychites Studeri.
6. Ceratites cassianus.
7. Trachyceras aon.
8. Halobia rugosa.
10. Myophoria Kefersteini.
11. Cidaris dorsata (spine).
12. Chemnitzia gradata.
14. Arcestes tornatus.
15. Pinacoceras Metternichi.
16. Tropites subbullatus.
22. Monotis salinaria.
23. Dadocrinus gracilis.

Anoplophora. There are many representatives of *Nucula*, *Avicula*, *Gervillia*, *Pecten*, and *Lima*, and the following genera make their

first appearance :—*Velopecten*, *Plicatula*, *Mytilus*, *Lucina*, *Sphæra*, *Cardita*, *Unicardium*, *Protocardium*, and *Homomya*.

The Brachiopoda include the last survivors of the ancient genera *Athyris*, *Cyrtina*, with some closely related but specially Triassic forms, such as *Koninckina*, *Thecospira*, and the Athyroids, which were formerly referred to *Retzia*, but which Bittner has separated under the names of *Plicigera* and *Pentactinella*. Besides these, species of *Terebratula* and *Rhynchonella* are abundant.

Among Echinoderms *Cidaris* and *Hemicidaris* make their appearance, and the Crinoid *Dadocrinus*.

Corals (Anthozoa) also occur, especially in the limestones of the Upper Trias, and belong chiefly to *Cladophyllia*, *Calamophyllia*, *Thecosmilia*, *Isastrea*, and *Thamnastrea*.

Calcareous algæ, however, are the chief limestone builders, and have been described under the names of *Diplopora* and *Gyroporella*.

Stratigraphy.—The Triassic system has no great thickness in the Central Alps, but attains a great development in the well-known Dolomite Mountains of the South Tyrol and Carnic Alps, and also in the Vorarlberg, in North Tyrol, Salzburg, and Bavaria, on the northern side of the main crystalline axis of the Alpine chain. The succession of beds forming the lower and middle parts of the system in the northern districts differs considerably from that in the southern, but the higher portions from the Raibl beds upwards are similar in both regions. Hence it has been inferred that there were at first two separate seas or marine provinces which were not united until the later part of the Triassic period ; the northern province has been called the Juvavian, and the southern the Mediterranean province.

The thicknesses of the several divisions vary much in different districts, but the total thickness in the North Tyrol is supposed to be about 6000 feet, while in the South Tyrol it is probably about 8000 feet. The following table shows the general succession in the two regions : [1]—

10. Upper Dachstein and Kossen beds with *Avicula contorta* (Rhætic).
9. Lower Dachstein or Great Dolomite with *Avicula exilis* and casts of large *Megalodons*.
8. Raibl beds, dolomitic marls and limestones with *Trachyceras aonoides*, *Myophoria Kefersteini*, and *Cardita Gumbeli*.

(Southern Province).	(Northern Province).
7. The Schlern dolomite, few fossils.	Upper Hallstadt limestones with *Tropidites subbullatus* and *Arcestes ruber*.
6. St. Cassian beds, marls with many fossils, *Trachyceras aon*, *Cassianella gryphæata*, *Cardita crenata*, etc.	Lower Hallstadt limestones with *Pinacoceras parma* and *P. Metternichi*.

(Southern Province).	(Northern Province).
5. Wengen beds with *Trachyceras archelaus* and *Halobia Lommeli*.	Zlambach beds with *Choristoceras Haueri*.
4. Buchenstein beds, *Trachyceras Curioni*.	
3. Mendola dolomite with *Ceratites trinodosus*.	
2. Virgloria limestone, *C. binodosus*.	Reifling limestone with *Ceratites trinodosus*.
	Guttenstein limestone, *C. binodosus*.
1. Werfen beds, red shales and sandy limestones with *Ceratites cassianus* and *Naticella costata*.	Gampil shales or Werfen beds with *Naticella costata*.

Of the ten groups above indicated No. 1 is regarded as the equivalent of the German Bunter, Nos. 2 and 3 of the Muschelkalk, Nos. 4 to 9 of the German Keuper, and No. 10 of the Rhætic Beds, which extend over Northern Europe. Mojsisovics has grouped the whole succession into five stages, but the delimitation of these is not very satisfactory. More recently he has proposed a series of zonal subdivisions characterised by special Ammonites, and these will probably be of much assistance in working out the comparative stratigraphy of the two regions.

2. The Trias of Germany and Britain

Passing northward from Austria and Hungary across Bohemia and Bavaria the Trias is found again in Southern and Central Germany, but there exhibits a very different facies. It consists largely of red marls and sandstones with deposits of gypsum and rock salt, beds which have evidently been formed in a large inland sea or salt-water lake. As already mentioned, the German Trias is everywhere divisible into three parts, known as the Bunter, the Muschelkalk, and the Keuper, and though the Muschelkalk may be considered a marine deposit because it contains fossils of the same marine genera which occur in the lower part of the Alpine Trias, yet this fauna is a small one so far as number of species is concerned. It is not the fauna of an open sea, but of an inland basin temporarily connected with the southern sea, and this fauna never penetrated into the British region.

Of more interest to British geologists are the remains of the terrestrial and lacustrine creatures which occur in the German Bunter and Keuper, because many of them have been found also in the British Trias. The following is a brief account of this fauna and flora, including both German and British fossils.

Life of the Northern Trias

Among plants the ferns are represented by the following genera: *Anomopteris*, *Clathropteris*, *Sagenopteris*, *Tæniopteris*, with

the Palæozoic *Pecopteris* and *Neuropteris;* conifers by *Voltzia* and *Albertia;* cycads by *Zamites, Otozamites, Pterophyllum,* and *Æthophyllum.* The horse-tail *Equisetum* is also found.

Mollusca are very rare, except in the Muschelkalk, though shells resembling *Unio* and *Anodonta* have been found. The small phyllopod crustacean *Estheria* is often very abundant.

Of fish the remains of many kinds occur, the more important

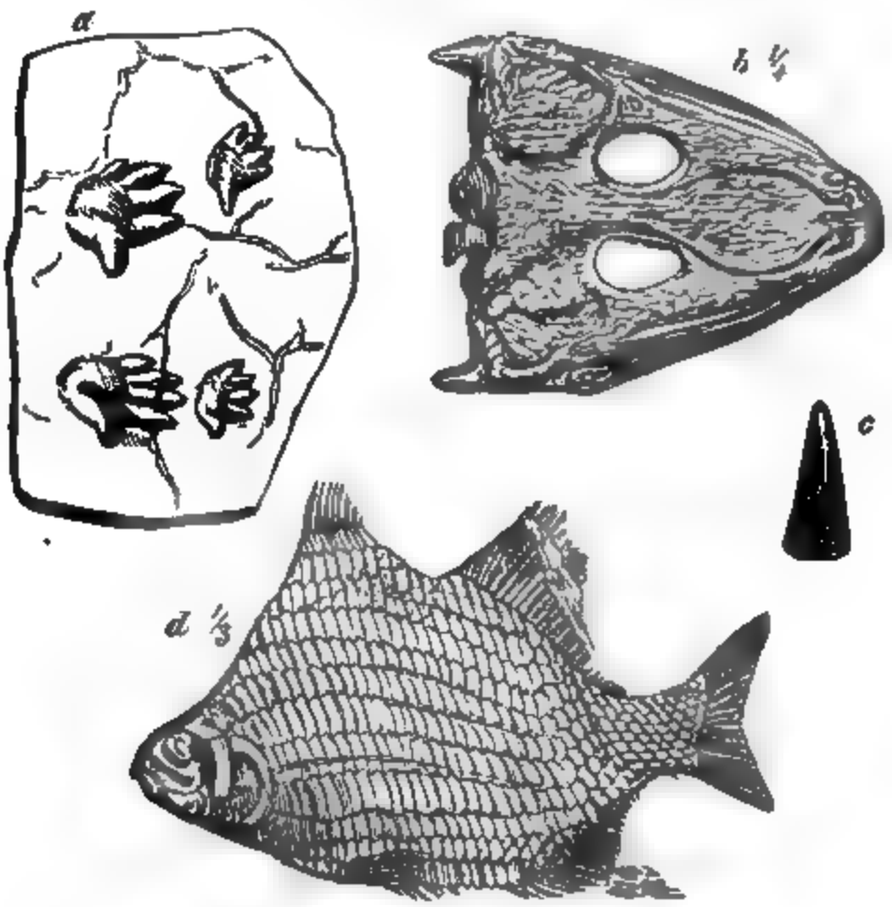

Fig. 95. GROUP OF TRIASSIC FOSSILS.
a, b, c. Footprints, skull, and tooth of Mastodonsaurus giganteus.
d. Dipteronotus cyphus.

genera being *Acrolus, Hybodus, Ceratodus, Dipteronotus, Gyrolepis Semionotus,* and *Saurichthys.* The ridged teeth of *Ceratodus* are abundant in some parts of the German Trias, and closely resemble those of the living species of that genus.

Amphibia are still represented by Labyrinthodonts, the chief genera being *Labyrinthodon, Mastodonsaurus,* and *Trematosaurus,* but this order does not survive the Triassic period. Their tracks are five-toed, like the rough impress of a man's hand.

Remains of true reptiles are not uncommon, and include

several of the orders which attained their maximum abundance in the succeeding Jurassic period. The Plesiosauria are represented by *Nothosaurus*, the Ichthyosauria by *Ichthyosaurus* and *Mixosaurus*, and the crocodiles by *Stagonolepis*, *Erpetosuchus*, and *Belodon*. Dinosaurs occur for the first time in the forms known as *Ornithosuchus*, *Palæosaurus*, *Teratosaurus*, *Thecodontosaurus*, and *Cladyodon*. Most of these creatures appear to have walked on their hind feet, after the fashion of a kangaroo; and as some of them had only three toes, their footprints greatly resemble those of gigantic three-toed birds, and were supposed for a long time to have been made by such birds; other genera had four or five toes.

But the most characteristic reptiles of the Trias are those belonging to the groups known as Placodontia, Rhynchocephalia, Dicynodontia, Theriodontia, and Pariasauria. The Dicynodonts were first discovered in South Africa, whence the typical genus *Dicynodon* was obtained, but more recently they have been found in Scotland, and two new genera—*Gordonia* and *Geikia*, together with the Pariasaur *Elginia*—have been based on the remains discovered in the sandstones of Elgin. The order Rhynchocephalia is represented by *Hyperodapedon*, *Telerpeton*, and *Rhynchosaurus*, and in New Zealand by *Sphenodon* (=*Hatteria*), the only genus represented by a living species. The Placodont genus *Placodus* is found in Germany.

The Trias has also yielded the earliest mammals which have yet been discovered, namely, the doubtful *Tritylodon* in the German Keuper, and the *Microlestes* of the Rhætic Beds, which are now generally classed as Triassic.

The following are some of the more characteristic fossils of the German and English Trias.

Fossils of the Bunter

Plants. Equisetum arenaceum, Voltzia heterophylla, Albertia elliptica, Æthophyllum speciosum.

Mollusca. (In Germany only) Myophoria costata, Gervillia Murchisoni, Pleuromya mactroides, Ammonites (Beneckea) tenuis.

Amphibia. Bones of Trematosaurus and Labyrinthodont footprints.

Fossils of the Muschelkalk

Echinoderma. Encrinus liliiformis.

Brachiopoda. Terebratula vulgaris, Plicigera trigonella, Rhynchonella decurtata.

Lamellibranchia. Myophoria vulgaris, Gervillia socialis Pecten discites, Lima striata, Trigonodus Sandbergeri.

Gastropoda. Natica gregaria, Pseudomelania scalata, Dentalium torquatium.

Cephalopoda. Nautilus bidorsatus, Ceratites nodosus, Beneckea Buchi.
Pisces. Ceratodus Kaupi, Hybodus major, Acrodus Gaillardoti.
Reptilia Placodus gigas, Nothosaurus mirabilis.

Fossils of the Keuper

Plants. Equisetum columnare, Pterophyllum Jægeri, Tæniopteris vittata.
Crustacea. Estheria minuta.
Mollusca. Myophoria Goldfussi, Anoplophora donacina (German).

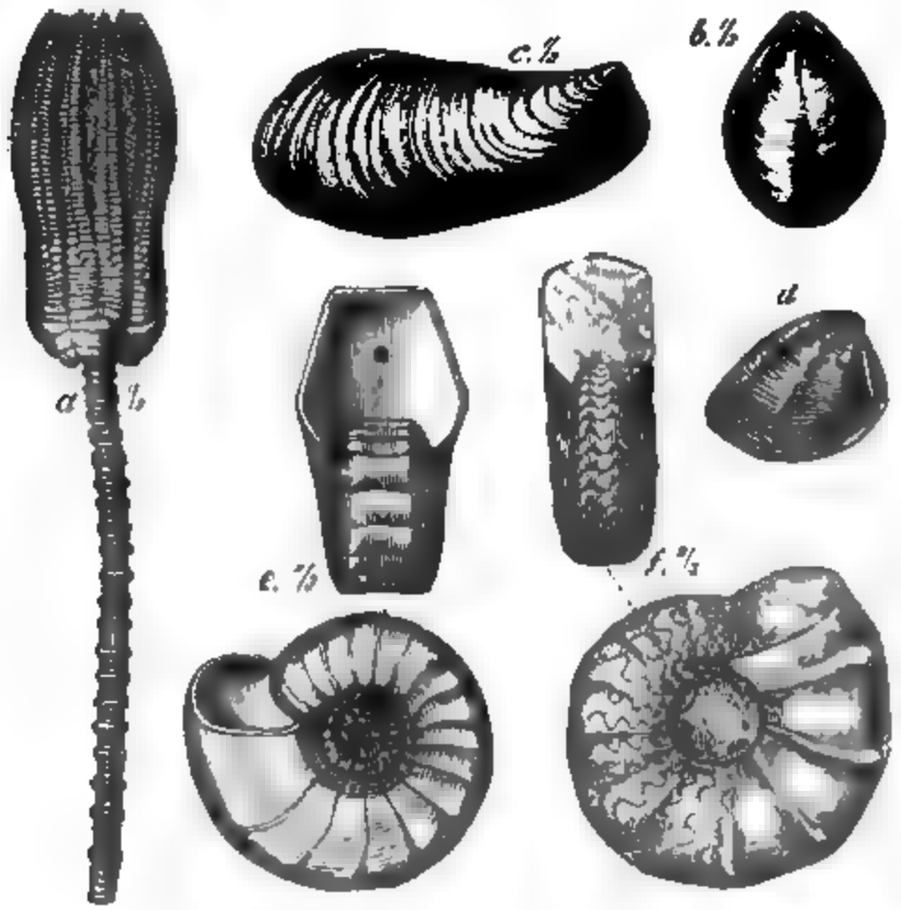

Fig. 96.—GROUP OF GERMAN MUSCHELKALK FOSSILS.

a. Encrinus liliiformis.
b. Terebratula vulgaris.
c. Gervillia socialis.
d. Myophoria vulgaris.
e. Nautilus bidorsatus.
f. Ceratites nodosus.

Pisces. Palæoniscus superstes, Acrodus minimus, Dipteronotus cyphus, Hybodus Keuperi, Semionotus Bergeri.
Amphibia. Mastodonsaurus giganteus.
Reptilia. Hyperodapedon Gordoni, Telerpeton elginense, Gordonia Traquairi, Elginia mirabilis.
Mammalia. Tritylodon Fraasi (German)

Fossils of the English Rhætic

Plants. Naiadita.
Brachiopoda. Orbiculoides Townshendi.

Lamellibranchia. Avicula contorta, Protocardium rhæticum, Pecten valoniensis, Anoplophora arenicola, Myophoria postera.
Pisces. Acrodus acutus, Ceratodus parvus, C. altus, Hybodus minor, Nemacanthus monilifer, Saurichthys apicalis.
Reptilia. Ichthyosaurus and Plesiosaurus.
Mammalia. Microlestes antiquus.

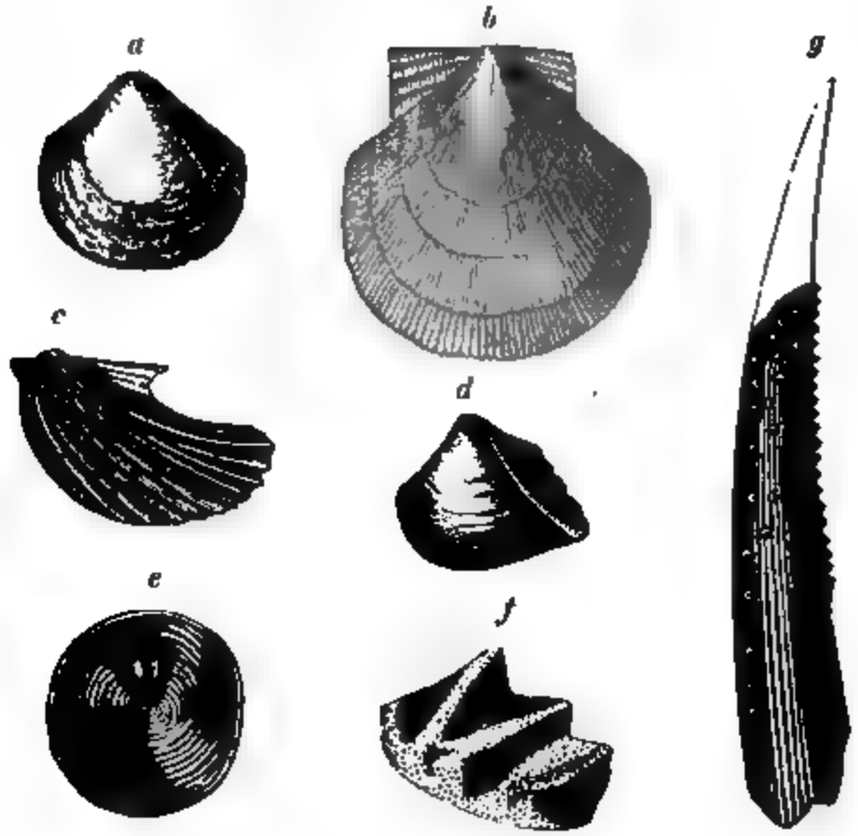

Fig. 97.—GROUP OF RHÆTIC FOSSILS.

a. Protocardium rhæticum.
b. Avicula contorta.
c. Pecten valoniensis.
d. Myophoria postera.
e. Orbiculoidea Townshendi.
f. Ceratodus parvus.
g. Nemacanthus monilifer.

STRATIGRAPHY OF THE GERMAN TRIAS

Triassic rocks occupy large areas in Central and Southern Germany, in Thuringia, Hesse, Franconia, Swabia, and Lorraine; they are also found in the Eifel district, in Hanover, Brunswick, and Magdeburg, and finally in the island of Heligoland. From the Rhine district they extend westward to Luxemburg, and through the Vosges Mountains into France. They are everywhere divisible into the three series of Bunter, Muschelkalk, and Keuper.[2]

Bunter.—This is essentially a sandstone series, and is divided into Lower, Middle, and Upper stages.

The lowest beds in Northern and Central Germany are dark red shaly sandstones, which succeed with apparent conformity the clays of the Upper Zechstein, but in Western Germany they overstep the whole of the Permian, and rest on the crystalline schists of the Odenwald and the Black Forest. The rest of the Lower Bunter consists of fine-grained micaceous sandstones of various colours, often speckled, and often including angular fragments of red clay; there are also some layers of dolomitic sandstone (*Rogenstein*). Fossils are rare. The maximum thickness is 500 feet.

The main mass of the Bunter Sandstone (or Middle Bunter) consists of coarse quartzose sandstones, which generally show current bedding and have a maximum thickness of 1000 feet. No fossils except tracks of Labyrinthodonts have been found.

The Upper Bunter or Röth consists of variegated red and green marls with beds of gypsum and rock salt, and is not more than 300 feet thick. In Thuringia these beds contain layers of dolomitic limestone with marine fossils (*Myophoria costata*, etc.). Westward in the Eifel, the Vosges, and Lorraine the Röth passes into fine argillaceous sandstones containing plant remains, *Voltzia*, *Equisetum*, and *Anamopteris*.

Muschelkalk.—This is a limestone series, and takes its name from the abundance of bivalve shells ("muscheln") in many of its beds. It has a thickness of from 600 to 1000 feet, and is divisible into three stages.

The lower beds consist of thin-bedded limestones (Wellenkalk) with yellowish porous limestones (Schaumkalk), and their chief fossils are *Myophoria orbicularis*, *Natica gregaria*, and *Dentalium torquatum*.

The middle part consists chiefly of dolomitic limestone and marl with beds of gypsum and rock salt. Fossils are rare.

The upper beds are hard limestones, consisting mainly of Encrinite stems, overlain by thin-bedded limestone containing *Ceratites nodosus* and other fossils.

In the Vosges country some of the Muschelkalk limestones are replaced by sandstones and marls, and the whole division gradually dwindles till it finally thins out and disappears.

Keuper.—In the German classification the Rhætic is included in the Keuper, which is then composed of three stages recognisable throughout Germany, namely :—

	Feet.
3. Rhætic beds	50 to 80
2. Keuper marls	500 to 1000
1. Kohlenkeuper	200 to 250

The Kohlenkeuper consists mainly of dark gray shales and

sandstones with thin beds of earthy coal. Some of the beds contain marine shells, others are crowded with *Estheria minuta*, and at the top is a yellowish dolomite containing *Myophoria Goldfussi* and other fossils.

The central beds, forming the main mass of the Keuper, are red and green marls with beds of gypsum in the lower part, and of rock salt in the upper. Fossils are rare in these marls except in South Germany, where some intercalated sandstones yield plants, fish, and the reptiles *Aetosaurus* and *Belodon*.

The Rhætic Beds consist of pale gray sandstones and shales containing *Avicula contorta* and other shells (see p. 304), with well-preserved plant-remains (ferns, cycads, and Equisetum).

It will be noticed that both the lower and upper stages of the Keuper contain marine fossils, though they are dwarfed and have the aspect of an inland-sea fauna.

Stratigraphy of the British Trias

Range and Relation to Rocks below

If the rocks described on p. 290 are truly of Permian age, the Trias enters England at Budleigh Salterton in Devon, and is exposed in cliff sections as far east as Axmouth, where it passes beneath the Lias. Inland it passes northward through Devon, Somerset, and Gloucester in a band of varying width, which sends prolongations westward on both sides of the Bristol Channel.

In North Somerset the upper beds of the Trias encircle the Mendip Hills, and occur in patches over the area of the Bristol coal-field. In the Severn valley its outcrop is narrowed by the overlap of the Lias, but widens again near Newent and Tewkesbury, running northward up the valley of the Severn, and spreading out eastward over large parts of Worcester, Warwick, Leicester, Stafford, and South Derby, interrupted only by island-like patches of the older rocks, which rise up from beneath it.

North of this great central expansion the Triassic area is divided into an eastern and a western fork by the range of the Pennine Hills, which were in existence before its formation. One tract extends through Nottingham and Yorkshire, forming a broad plain between the magnesian limestone and the Lias as far as York; thence it narrows, but runs up the valley of the Ouse and across that of the Tees to the coast at and south of Hartlepool. The other tract extends from Staffordshire through Shropshire, Cheshire, and Lancashire to the shores of Morecambe Bay, along

the western side of Westmoreland, and bordering the Solway Firth inland as far as Carlisle and Longtown. An outlying tract of Trias occurs in North Wales (Vale of Clwyd).

In Scotland there are small tracts in Dumfriesshire, some scattered patches in the Western Isles, and a tract on the south shore of Moray Firth (Elgin and Ross).

In Ireland, Trias is found only in Ulster (Antrim, etc.), and does not occupy any large area at the surface, though it probably extends beneath the chalk and basalt of the former county.

With regard to the eastward subterranean extension of the Trias in England, we know that it thins out against the plateau of Palæozoic rocks which underlies the east and south-east of England. Thus borings near Northampton proved the Trias (Keuper only) to be very thin there (only 60 to 70 feet), while borings in the east of England, at Culford near Bury St. Edmunds, at Ware, Turnford, London, and Dover, have proved its absence. At Burford in Oxfordshire a thickness of 424 feet of Trias was found with Coal-measures beneath it, so that it probably extends beneath the greater part of Oxfordshire, and in all probability it thins out on the rising surface of the Palæozoic rocks about the longitude of Thame and Reading.

Recent researches have tended to show that the break between the Permian and the Bunter is not of such magnitude as was formerly supposed; still there is a decided unconformity, and it is probable that great physical changes took place in the interval. Taken as a whole the Trias is unconformable to all older formations; it extends far and wide beyond the edges of the Permian beds, and runs up many of our wider valleys, as if the principal hill-ranges of England were then already in existence, as indeed they doubtless were. The Coal-measures and older Palæozoic rocks had been bent into troughs, basins, and ridges, and had suffered enormously from erosion and detrition before the Triassic beds were deposited upon them, so that in most parts of the country these beds rest upon a surface of erosion which had been previously formed across the tilted edges of the Palæozoic rocks.

In giving some account of the rocks which make up the extensive areas of Trias in England it will be convenient to describe them under five heads or districts: (1) The south-western district, including Devon, Somerset, Gloucester, and Glamorgan; (2) the Midland district; (3) the north-eastern or Nottingham and Yorkshire; (4) the north-western, Cheshire and Lancashire; (5) the Carlisle basin.

1. *South-Western District*

The beds exposed on the south coast of Devon between Budleigh Salterton and the great landslip near Axmouth are divisible as follows :—

		Feet.
Keuper	Rhætic beds	63
	Red and green marls	about 1150
	Red and gray sandstones	,, 75
Bunter	Coarse red sandstones with pebbles	,, 300
	Conglomerate or "pebble beds"	,, 80
		About 1660

Bunter.—The dark red marls which have been described as Permian may possibly be of Triassic age, but if not the pebble beds form the base of the Bunter in Devonshire.[3] These beds are conspicuous in the cliff west of Budleigh Salterton (see Fig. 98), and consist of well-rounded oval pebbles of quartzite and hard grit embedded in a matrix of red sand ; they exhibit current bedding and include lenticular layers of sand. Some of the pebbles contain Devonian fossils, and others are Silurian and Ordovician, resembling the Grès Armoricain and the Grès du May of Brittany and the Ordovician rocks of Cornwall. Dark, compact, tourmaline rocks also occur, like some which occur in the metamorphosed zones round the granite masses of Devon and Cornwall.

According to Professor Bonney, however, the majority of the pebbles do not resemble Devon and Cornwall rocks, while quartz-felspar grits, some corresponding exactly with the Torridonian of Scotland, are not rare. When the beds are traced northward the pebbles become smaller, and they gradually pass into a sandy conglomerate with small pebbles of grit and quartz.

The sandstones above are coarse current-bedded red sandstones, and in the lower 100 feet they contain pebbles of quartz and quartzite, with subangular fragments of granite, felspathic grit, and lumps of hard red marl. The higher beds are less coarse and more massive, and from these bones of *Hyperodapedon* have been obtained. These beds occupy the coast from the mouth of the Otter to Sidmouth.

Keuper.—According to Professor Hull and Rev. A. Irving the base of the Keuper division should be taken at a bed of hard breccia about two feet thick, which can be seen below the footbridge over the Sid at Sidmouth. Above this are pale red and gray sandstones with seams of marl, succeeded by alternating bands of sandstone and marl, the beds, in which sandstones predominate,

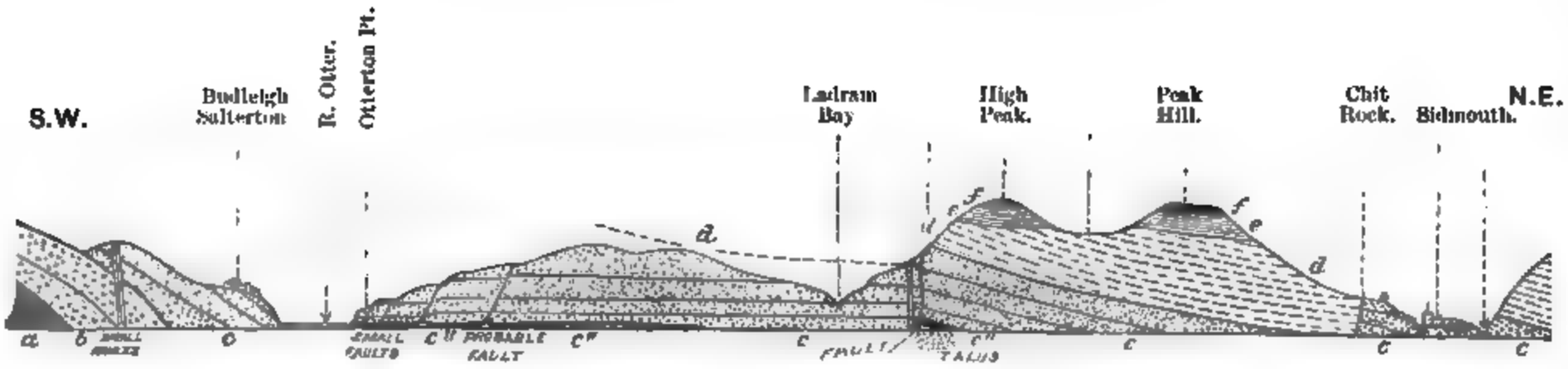

Fig 98.– SECTION ALONG THE COAST OF DEVON, FROM BUDLEIGH TO SIDMOUTH (A. T. Metcalfe). Distance about 5 miles.

f. Clay with flints.
e. Upper greensand.
d. Keuper marls.
c. Keuper sandstone.
c''. Bunter sandstones.
b. Pebble beds (Bunter).
a. Red marls (? Permian).

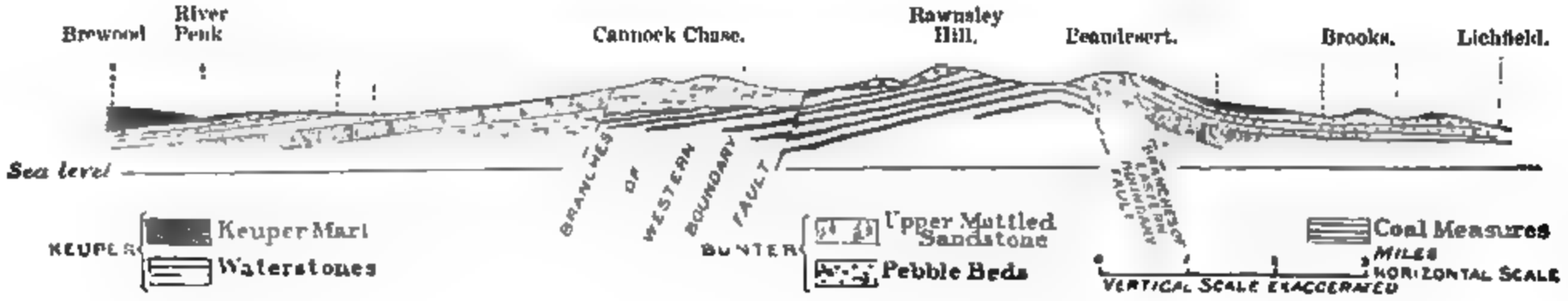

Fig 99.—SECTION FROM BREWOOD TO LICHFIELD ACROSS THE NORTH END OF THE SOUTH STAFFORDSHIRE COAL-FIELD (by Professors Lapworth and Watts). Distance about 16 miles.

being about 75 feet, and being regarded as Lower Keuper sandstone.

The succeeding beds are red marls with thin sandstones in the lower 150 feet, but passing up into massive marls with a conchoidal fracture containing strings of gypsum and pseudomorphs of rock salt. These form the lower part of the cliffs as far as Branscombe mouth, but near Beer Head a syncline carries them below the beach. Higher beds occur in the Axmouth and Bindon cliffs, where they finally pass up into the Rhætic beds, the succession of the highest beds seen near Culverhole Point being as follows :—

		Feet.
Rhætic Beds	Thin whitish limestones (White Lias)	15
	Black shales with a bone bed at base	18
	Green and cream-coloured marls with layers of marly limestone and of black clay	30
	Red and green marls	seen for 20

The black shales yield many of the characteristic fossils, such as *Avicula contorta, Protocardium rhæticum*, etc.

A boring has recently been made at Lyme Regis to test the depth of the red marls at that place, and in the vain hope that coal might be found below ; after passing through 85 feet of Lias and 67 feet of Rhætic beds, red and green marls were traversed to a depth of 1300 feet, when the boring was abandoned.

When the Bunter Beds are followed inland they become thinner, and in Somerset they thin out and are overlapped by the Keuper division, so that in North Somerset, Gloucester, and Glamorgan only the upper division of the Trias is found.

Around the Mendip Hills and in the Bristol district, wherever the old Palæozoic surface is exposed, the basement beds of the Keuper are conglomerates of a peculiar kind. They consist mainly of pebbles of Carboniferous limestone, the majority as large as a hen's egg, but ranging up to boulders of two or three feet diameter ; these are held together by a calcareous cement or matrix, generally dolomitic, so that the beds are known as the Dolomitic Conglomerate. Calcareous sandstones are sometimes associated with it, and it passes beneath the red (Keuper) marls which form the Triassic tracts, here shown on a geological map.

The conglomerates are not, however, as a whole older than the marls, for they occur at all horizons along the margin of that deposit, and dovetail into it (see Fig. 68, p. 214). They are in fact the ancient beaches formed during the gradual submergence of the area in Upper Triassic times.

The **Rhætic Beds** are exposed near Watchet in West Somerset,

at Penarth in Glamorgan, at Uphill near Weston-super-mare, at Austcliff and Westbury on the estuary of the Severn. They vary in thickness from 30 to 70 feet, but the three subdivisions of (1) gray marls and shales, (2) black shales, (3) white limestones and marls, are generally present. The following table shows the relative thicknesses in feet at the localities mentioned :—

	Watchet.	Penarth.	Weston.	Austcliff.	Westbury.
White Lias	10	18	12	10	10
Black shales	22	22	25	12	26
Gray marls	32	28	30	?3	18

The gray marls seldom yield fossils, and are really passage beds from the red Keuper into the Rhætic Beds. The black shales generally contain one or two sandy layers near the base, which are crowded with the teeth, scales, bones, and coprolites of fish and reptiles, and hence are known as "bone beds." The shales contain *Avicula contorta*, *Pecten valoniensis*, and other fossils. The upper member consists of marly limestones, white or cream-coloured, the topmost bed being a hard, compact, and smooth-grained limestone known as the "sun-bed."

At certain places on the Mendip Hills sandy deposits and conglomerates occur, marking the shore line of the Rhætic Sea; and some fissures in the Carboniferous limestone at Holwell, near Frome, have yielded an immense number of Rhætic fossils (teeth and bones of fish, reptiles, and *Microlestes*).

2. *Midland District*

This district will be regarded as including the counties of Worcester, Warwick, Leicester, Stafford, Salop, and a small portion of Derbyshire. The following is the general succession and average thickness of the beds which constitute the Trias in North Worcestershire between Droitwich and Kidderminster :[4] —

		Feet.
Keuper.	Rhætic Beds	40 to 50
	Red and variegated marls with rock salt and gypsum	1000
	Red micaceous sandstones with red breccia and conglomerate at the base	300
Bunter.	Upper mottled sandstone	200
	Pebbly sandstone and conglomerate	300
	Lower mottled sandstone	200
		About 2000

Bunter Division.—The upper beds of the Bunter emerge

from beneath the overlap of the Keuper near Great Malvern, but the lowest beds only make their appearance to the north of Bewdley and Kidderminster. The Lower Sandstones are generally of a reddish brown colour, but sometimes bright red or yellow or mottled with these colours. They are devoid of pebbles and always exhibit much current bedding. They attain their greatest thickness (650 feet) at Bridgenorth in Salop.

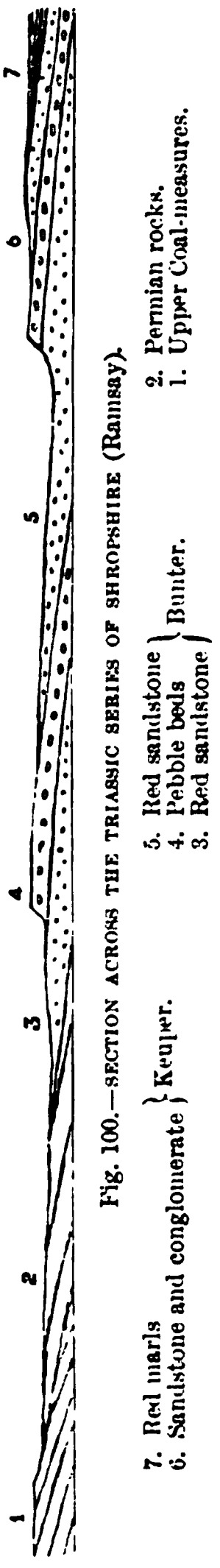

Fig. 100.—SECTION ACROSS THE TRIASSIC SERIES OF SHROPSHIRE (Ramsay).

The Pebble Beds which form the central group of the Bunter are most fully developed in East Shropshire and South Staffordshire. They pass northward beyond the outcrop of the Lower Sandstones, resting unconformably on the Permian, and finally on the Coal-measures of Cannock Chase (see Fig. 98). In this central area they form a mass of conglomerate which is from 300 to 400 feet thick, and consists of well rounded pebbles, the majority of these being brown and chocolate-coloured quartzites, with which, however, are pebbles of Carboniferous limestone and sandstone, of purple grit, and of some volcanic rocks. At the surface the sandy matrix is generally soft, but when traversed in deep borings it is very hard and highly calcareous. Near Bridgenorth it has a breccia of angular fragments at its base, about 60 feet thick, but this does not seem to extend far.

The Upper Mottled Sandstone resembles the Lower Sandstone, but is generally of a bright red colour, and is more often variegated with yellow and white. It underlies the towns of Stourport, Stourbridge, and Birmingham, but no fossils have been found in it.

All the divisions of the Bunter thin out as they are traced from west to east, or from north-west to south-east—a fact which may be taken as proof that the pre-Triassic floor sloped upwards toward the east and south-east. The following table indicates this easterly overlap and diminution of thickness:—

	Shropshire.	West Side of South Staffordshire Coal-field.	East Side of South Staffordshire Coal-field.	North Warwick.
Upper Sandstone .	500	300	100	Absent
Pebble Beds . .	400	300	200	Absent
Lower Sandstone .	650	0 to 100	Absent	Absent
	1550	700	300	nil

Keuper Division.—The Lower Keuper sandstones, where fully developed, are divisible into three stages, the lowest consisting of coarse sandstones with calcareous breccias and cornstones, the middle part of fine-grained sandstones capable of use as building-stone, while the upper beds are laminated sandstones, locally called "waterstones," from their yielding good water in wells and borings. These sandstones have yielded bones and teeth of *Labyrinthodon*, *Cladyodon*, and *Hyperodapedon*, and the fish *Dipteronotus cyphus*.

Professor Lapworth remarks[4a] that in Shropshire and West Staffordshire the general relation of Keuper to Bunter is that of conformity, though the surface of the Bunter is eroded, while east of the "Black Country" the basement breccias are often wanting, and sometimes there seems to be a real unconformity between the two divisions; finally, round the Warwickshire Coal-field the Keuper sandstones are much thinner and rest directly on the Palæozoic rocks.

The Keuper Marls occupy large areas in Worcester, Warwick, and Leicester. They form the thickest and in some respects the most important member of the Triassic system, but lithologically it is uninteresting, the greater part consisting of red marls and shales without fossils. The higher beds, however, include a band of gray sandstone (20 to 30 feet thick), known as the Shrewley sandstone, which has yielded remains of fish (*Palæoniscus superstes*) with *Estheria minuta* and some casts of bivalve Mollusca.

The red marls everywhere contain seams and nodular bands of gypsum, and in Worcestershire, between Droitwich and Stoke, they include a thick and valuable bed of rock salt. These marls are thickest in the west, being probably from 1500 to 1800 feet thick in Shropshire, 700 to 800 feet in Staffordshire, and about 600 in Warwick and Leicester, where they overlap the underlying sandstones and are banked against the pre-Cambrian rocks of Charnwood Forest, partially filling the valleys between the hills.

The Rhætic Beds form a narrow but continuous band between the red Keuper Marls and the dark clays of the Lias, but

they are rarely exposed in Worcester or Stafford. In Warwickshire there are exposures of the White Lias at Knowle (near Solihull) and at Harbury, Rugby, Southam, and Eatington, and a good section has been described at Wigston, near Leicester, where the following succession was seen :—

	Feet.
3. Blue shales with two thin beds of limestone and sandstone .	22
2. Black shales containing *Schizodus cloacinus, Protocardium rhæticum, Avicula contorta,* and fish teeth	18
1. Light gray marls passing down into red marls	15

3. *North-Eastern District*

In Leicestershire the Bunter is only represented by pebble beds of irregular extent and thickness, but sometimes as much as 200 feet. Near Nottingham, however, the lower sandstone sets in again, and thence the Bunter thickens northward, forming a continuous strip between the Permian and the Keuper. The upper mottled sandstone is, however, absent throughout this eastern area. Near Nottingham the succession is as follows (see Figs. 101, 102) :—

		Feet.
Keuper	Rhætic shales and limestones	30 to 46
	Red marls with much gypsum, and beds of sandstone near the base	600
	Waterstones with pebbly or conglomeratic base .	80
	White sand and pebble beds	up to 100
Bunter	Coarse and pebbly sandstones	200
	Lower mottled sandstone	25 to 100
		About 1000

Bunter.—The Lower Sandstone is of a bright red or orange colour ; it is traceable into Yorkshire as far as a cutting on the railway east of Knaresborough, beyond which it is either absent or is indistinguishable from the sandstones which there overlie it.

The Bunter Pebble Beds form the rock on which Nottingham Castle stands, where they consist of a coarse yellowish sandstone full of quartzite pebbles. They range northward through Sherwood Forest, by Worksop, Tickhill, and Doncaster, but it is doubtful whether they extend far beyond the last place. The sandstone passes sometimes into loose red and yellow pebbly sands, and sometimes into a hard conglomerate. The pebbles are everywhere the same, principally quartzite and quartz, with a few fragments of soft sandstone and black chert.

In the northern part of Yorkshire the following ascending sequence is found : (1) Red marls with rock salt and gypsum, 200 to 450 feet ; (2) red and white sandstones with bands of red marl in the lower part, 800 to 900 feet. How much of this series

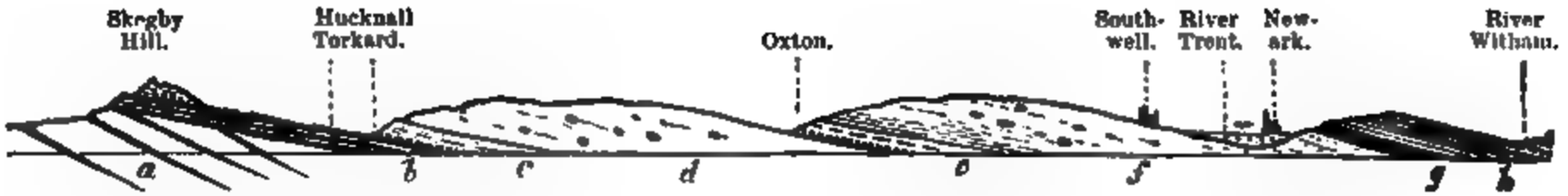

Fig. 101.—SECTION THROUGH SOUTH NOTTS, FROM THE EREWASH TO THE WITHAM (by Rev. A. Irving). Distance about 22 miles.

h. Lower lias.
g. Rhætic beds.
f. Keuper marls.
e. Keuper sandstone.
d. Bunter conglomerate (pebble beds).
c. Lower Bunter sandstone.
b. Permian rocks (magnesian limestone, etc.)
a. Coal-measures.

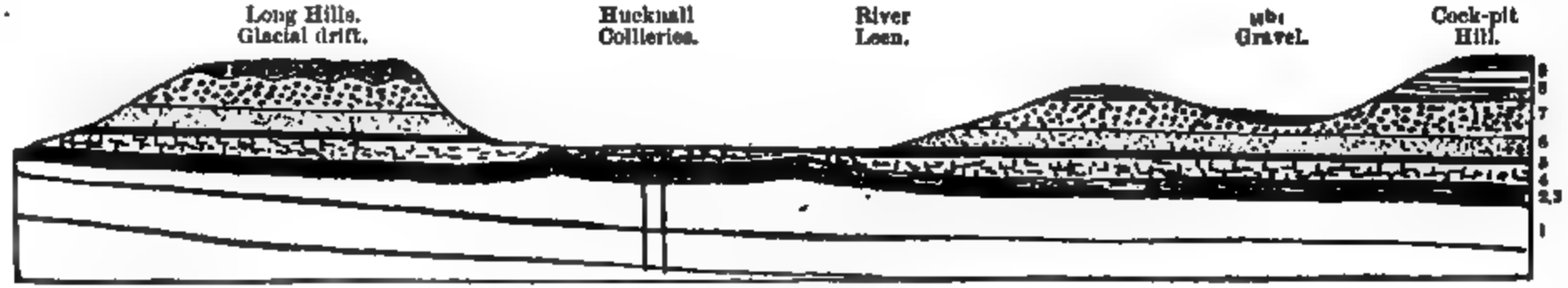

Fig. 102.—SECTION ACROSS THE VALLEY OF THE RIVER LEEN NEAR HUCKNALL TORKARD (J. F. Blake). Distance 6 miles.

9. Red marls.
8. Waterstones.
7. Pebble beds (Bunter).
6. Lower Bunter sandstone.
5. Red marl (Permian).
4. Magnesian limestone.
3. Marl-slate } Permian.
2. Breccia }
1. Coal-measures.

should be assigned to the Bunter is uncertain, but it seems probable that the reds marls and the greater part of the sandstones are referable to the Bunter.

Keuper.—The basement bed of the Keuper division near Nottingham is an irregular deposit of white sand, which rests on an eroded surface of the Bunter pebble beds, and varies from a few inches to many feet in thickness. Mr. J. Shipman has described certain pebbly sandstones more than 100 feet thick, which he regards as representing this deposit.[5]

The Waterstones which succeed generally have a pebbly or conglomeratic bed at the base, and this rests sometimes on the white sand deposit, and sometimes directly on the Bunter, but always on an eroded surface, so that it seems to be unconformable to the beds below. The pebbles are chiefly quartz and quartzite, but Mr. Shipman has detected fragments of trap, slate, chert, and magnesian limestone. The waterstones themselves consist of soft brown sandstones interstratified with red marls, which cause plentiful springs by throwing out the water collected in the sandstones. Ripple-marks and sun-cracks are frequent in these beds.

There is no marked line of division between the Waterstones and the Keuper Marls; the marl bands become thicker, but still contain beds of sandstone in the lower 150 feet, though these sandstones are harder and generally white or bluish gray. Gypsum occurs in the marls, and the higher beds are chiefly marl with sheets and nodules of gypsum.

In Yorkshire the Keuper appears to become thinner, and not to exceed 700 feet in thickness; it is still capable of division into an upper red marl group, about 400 feet thick, and a lower series of red and white sandstones from 200 to 300 feet thick, but, as above mentioned, its lower limit is somewhat uncertain in the northern part of the county.

Rhætic Beds.—These present their usual facies, and persist as a narrow band below the Lias through the counties of Leicester, Lincoln, and York. The gray marls are from 12 to 15 feet, the zone of *Avicula contorta* is from 10 to 18 feet thick, and the white Lias from 10 to 20 feet. Good sections occur near Leicester.[6] In Yorkshire there are some inland exposures, but the beds are not seen on the coast section.

4. *Cheshire and Lancashire*

The Trias of these counties is a continuation of the Shropshire series, but attains a greater development, the average thickness of the several stages being as follows:[7]—

		Feet.
Keuper, 2400 feet	Rhætic beds	30 to 40
	Marls and upper sandstone	2000
	Lower sandstones (waterstones)	400
Bunter, 2000 feet	Upper mottled sandstone	600
	Pebble beds	1000
	Lower mottled sandstone	400
		4440

Bunter.—Near Chester the lowest beds are seen to rest on the purple shales and sandstones of the Millstone Grit, the basement being a dark purple breccia (10 feet thick), passing up into coarse sandstones, soft, and coloured red, yellow, and white. This division ranges northward to the Mersey, and then eastward along the south border of the Lancashire coal-field, but thins in that direction and does not occur at Manchester or Stockport.

The Pebble Beds are well seen at Holt, on the river Dee, where their base is a breccia, succeeded by soft red-streaked sandstone overlain by pebbly sandstone, the whole series resembling that at Bridgenorth. Near Liverpool and St. Helens they attain a great thickness, consisting of two parts—(1) hard red-brown pebbly sandstones, about 600 feet thick, and (2) hard reddish sandstones without pebbles, about 400 feet. Eastward, by Wigan, Manchester, and Stockport, they overlap the lower mottled sandstones, so as to rest on the Dyassic and Carboniferous rocks.

The Upper Mottled Sandstone ranges along the flanks of the Peckforton Hills, through Delamere Forest, to Runcorn and Warrington, and thence through West Lancashire by Liverpool and Ormskirk. Its only peculiarity is that while the lower part is of the usual red colour streaked with white, the upper part is of bright yellow.

These Bunter Sandstones extend northward by Ormskirk, Preston, and Garstang, whence they pass beneath Morecambe Bay. They emerge again in the promontory of Furness, and extend northwards to St. Bees in Cumberland (see map, Fig. 32).

Keuper Division.—The basement bed of this division is always pebbly, and sometimes (as at Peckforton) becomes a hard calcareous conglomerate. This is succeeded by hard red, yellow, and white sandstones (200 feet thick, and quarried for building stone), above which are the Waterstones—brown micaceous flagstones, with red and gray shales at their base (200 feet in Delamere Forest and at Liverpool).

The Peckforton Hills rise to heights of 800 and 900 feet, and a series of strike-faults has led to the development of a succession of nearly parallel escarpments, the western slopes of which consist of the

soft Bunter sandstone, while the rock forming their summits is the hard basement conglomerate of the Keuper.

The upper red and gray marls contain, as elsewhere, layers of gypsum and beds of rock salt from 70 to 100 feet thick. These are worked by shafts and pits at Northwich, but elsewhere it is obtained in the form of brine from borings, the water percolating through the beds, dissolving the salt and being pumped up the bore-hole. The thickness of these saliferous marls in Cheshire is very great, and may be even more than 2000 feet (see Fig. 85). They pass northward through Lancashire to Fleetwood or Morecambe Bay, and a small tract of red marl occurs in Furness on the other side of this bay.

Rhætic Beds.—The only part of this area where these beds have been found is round the outlier of Lias, which occurs between Wem and Audlem, on the borders of Shropshire and Cheshire. Mr. G. Maw described [8] sections near Audlem which showed the following beds :—

	Feet
3. Dun-coloured sandy shales with thin layers of limestone at the top, *Pullustra arenicola*, *Pleuromya anconoides* . . .	9
2. Black flaky shales abounding in *Avicula contorta* . . .	23
1. Light buff-coloured marl without fossils	6

5. *The Carlisle Basin*

Triassic rocks underlie a considerable area in the north of Cumberland, from the coast near Maryport eastward to Carlisle and Longtown, and thence they extend southward down the valley of the Eden (see map, Fig. 32). From Longtown they extend westward along the northern shore of the Solway Firth to and beyond Annan. This Solway and Carlisle area forms part of an oval basin, the highest beds lying in the central part, and the lowest forming an outer encircling zone. The western part of the basin has been invaded by the sea, but there is no doubt that the red sandstone of St. Bees originally stretched northwards to Maryport, and there may still be an actual submarine connection of one tract with the other.

The Trias of Cumberland is divisible as follows :—

		Feet.
Keuper	Red marls with gypsum	950
	Kirklinton sandstone	500
Bunter	St. Bees sandstone	1000 to 1500
	Red gypsiferous marls	up to 300
		Maximum 3200

Bunter.—The lower red marls, according to Mr. J. G. Goodchild,[9]

lie unconformably on the Permian beds (see p. 285). They vary in thickness from 100 to 300 feet, contain much gypsum, and pass up by intercalation of sandstone beds into the sandstone above.

The St. Bees Sandstone represents the Pebble Beds and the Upper Sandstone of Lancashire. It occupies the coast between Maryport and Allonby, and thence extends eastward by Wigton to the valley of the Eden, but, curving northward by Brampton, passes beyond the lower marls and the Penrith Sandstone till it rests directly on the Carboniferous rocks of the Scottish border. Its lower part is a variegated sandstone, but the greater part is of dull, uniform, brick-red colour. It contains some bands of pebbly sandstone, but the only relics of contemporary life are reptilian footprints.

Keuper.—The Kirklinton Sandstone is only seen in the eastern part of the basin, its outcrop elsewhere being concealed by the Drift deposits. It consists of soft sandstones, which are in some parts red, in others white, or sometimes mottled red and white, and they are probably the equivalents of the Cheshire "water-stones."

The Keuper Marls are also for the most part buried beneath Drift, but near Carlisle the sandstones are covered by red and gray marls, which are exposed in several places on the banks of the Eden. West of Carlisle there is believed to be a fault of considerable magnitude, for borings have shown that a great thickness of red shaly marls with gypsum and rock salt is brought into the western and deeper part of the basin; thus a boring at Abbey Town proved over 700 feet of red marl with red (? Kirklinton) sandstone below.

Whether Rhætic Beds exist in this district is not yet known for certain, but as there is an outlier of Lias in the centre of the basin it is very probable that the usual band of Rhætic intervenes, especially as they occur both in Ireland and in Scotland.

6. *Southern Scotland*

Several tracts of red sandstone occur in the south of Scotland, and undoubtedly belong to some part of the "New Red Sandstone," but owing to the paucity of organic remains it has been very difficult to determine their precise age. In early days they were referred to the Trias, but afterwards and until quite lately they were generally regarded as Permian; recent opinion, however, is in favour of considering them all to be of Triassic age.

There are no fewer than seven such tracts in the southern part of Scotland—namely, two in Annandale and two in Nithsdale (Dumfriesshire), one in Ayrshire, one on Loch Ryan in Wigtown-

shire, and one in the Isle of Arran. The beds lie unconformably on all older rocks, including the Carboniferous.

Dumfries.—In this district the three largest tracts are (1) one extending from the Solway Firth by the mouth of the Nith to and beyond the town of Dumfries, (2) round Lochmaben in Annandale, and (3) round Thornhill in Nithsdale. Professor Harkness was of opinion [10] that the general succession of the beds near Dumfries and Lochmaben was as follows :—

	Feet.
4. Thin-bedded sandstones with beds of clay . .	300
3. Hard massive breccias and conglomerate . . .	300
2. Soft red current-bedded sandstones 1. Coarse sandstones and breccias . . .	500

The breccias consist of angular blocks and fragments of various Palæozoic rocks, with some of granite and other igneous rocks, embedded in red sand. The lower sandstones are brick-red in colour, frequently flaggy and divided by thin seams of dark-red clay, and their surfaces often bear the footprints of Labyrinthodont and other reptiles. Such footprints were first described by

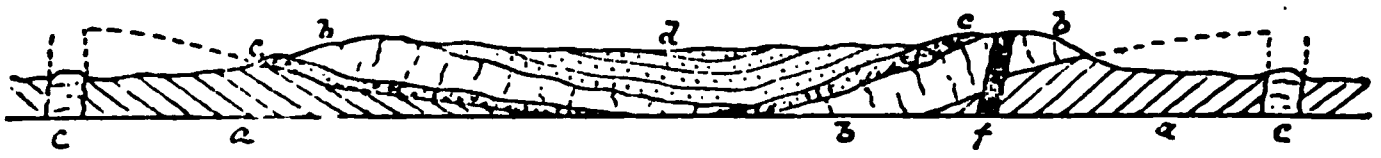

Fig. 103.—SECTION ACROSS THE TRIASSIC BASIN IN AYRSHIRE.

f. A dyke of basalt.
c, e. Volcanic necks.
d. Red sandstones.
c. Beds of volcanic tuff.
b. Lava-flows.
a. Carboniferous rocks.

Professor Buckland from specimens found in the quarries on Corncockle Moor, near Lochmaben, but they are equally common near Dumfries; they also occur in the upper sandstones, the beds of which are separated by rather thicker layers of clay.

It is possible that only the upper breccias and sandstones are of Triassic age, the lower beds being Permian and comparable to the Penrith sandstone.

In the Thornhill basin, farther north, there are no breccias, and the greater part of the tract consists of brick-red sandstone, but in the northern part lava-flows and volcanic detritus are interstratified with the lowermost sandstones (see p. 323). The higher sandstones contain beds of shale and clay, and seem comparable to the higher beds near Dumfries.

Ayr.—In the centre of the Ayrshire coal-field near Mauchline lies a pear-shaped area, occupied by rocks similar to those of Thornhill (see Fig. 103), and associated with the volcanic breccias of this district are some beds of a purple sandy limestone, but no fossils have been found in them.

Arran.—Red rocks of Triassic age occupy a considerable area in the southern part of Arran, and consist of conglomerates and sandstones overlain by red shales and marls. Moreover, recent exploration of the agglomerates which fill up the vent of a huge Tertiary volcano in this part of the island have led to the discovery of large masses of rock which show a sequence from red marl through Rhætic shales into Lower Lias, thus proving the red marls to be of Keuper age, and to have been succeeded by Rhætic and Liastic beds, though all other traces of these beds have been destroyed by erosive and detritive agencies during Tertiary times.[11]

7. *Northern Scotland*

Beds which are unquestionably of Triassic age occur both on the western and eastern coasts of Scotland.

Western Coast.—Small patches of Trias occur at the base of the Neozoic rocks in Morvern and Ardnamurchan (Argyleshire), in the isles of Skye and Raasay, and on the coast of Gruinard Bay in Ross-shire.

The following account is taken from Professor Judd's description.[12] The materials forming the breccias, conglomerates, and coarser sandstones have evidently been derived from the older rocks on which these strata repose, usually either the Torridon sandstone or some member of the Highland gneissic series. A special feature in the Triassic rocks of this region is the abundance of calcareous matter which enters into their composition; fragments of compact limestone (? Durness limestone) abound in the coarser beds; the sandstones often pass into calcareous grits, and bands of cornstone are not unfrequent, while all the beds are frequently traversed by veins of calcspar. As a rule breccias and conglomerates prevail in the lower part of the series, sandstones, marls, and limestones in the upper part, but the succession of beds is very irregular and inconstant. At Gruinard Bay the total thickness exceeds 1000 feet; at Raasay it is probably less than 500 feet, though the general succession is the same; at Lussay, in Skye, it is reduced to a few feet, and southward, in parts of Mull and Morvern, it varies from 50 to 500 or 600 feet.

The following is the succession at Gruinard Bay :—

	Feet.
Soft reddish argillaceous and sandy beds with bands of hard white and greenish sandstone	200
Red and variegated marls with thin beds of sandstone and concretionary limestone	200
Red argillaceous sandstones and conglomerates, alternating in the lower part with masses of coarse breccia-conglomerate . . .	500

In Morvern the concretionary cherty limestones which occur in the marly division are somewhat thicker, and resemble the limestones of Elgin mentioned below. No fossils have been found except some casts of bivalves (? *Cyrena*) in sandstone at Ardtornish. No Rhætic beds have yet been identified on the western coast, but it is only in Raasay that the junction of Trias and Lias has been found, and the section there is obscure at this point.

Eastern Coast.—Small tracts of Trias occur on the coast of Moray north of Elgin, and near Dunrobin Castle in Sutherland. The former is important because it has yielded the bones and skulls of many remarkable reptiles (see p. 202).

The reptiles belong to the genera *Stagonolepis*, *Hyperodapedon*, *Telerpeton*, *Erpetosuchus*, *Ornithosuchus*, *Elginia*, and the Dicynodonts *Gordonia* and *Geikia* which were described by Mr. E. T. Newton in 1893.[13] Teeth of the fish *Ceratodus* also occur.

The reptiliferous sandstone rests unconformably upon the Upper Old Red Sandstones of Moray, and the beds are repeated by a fault, so that they form two parallel ridges ranging from N.N.E. to S.S.W. for a distance of about nine miles. The more northerly ridge runs parallel to the coast from Branderburgh to Burghead, and the southern or inland ridge passes a little to the north of Elgin. These two ridges are separated by a tract of low ground about three miles wide and covered by Drift deposits. The Old Red Sandstones containing *Holoptychius* and other fish-remains crop out on the south slopes of the ridges, and the reptiliferous sandstones are quarried on the northern slopes. At the base of the latter is a pebble bed or conglomerate about four feet thick, consisting of rounded pebbles of white and purple quartz. This passes up into coarse yellow and white sandstones, and it is from these sandstones that the reptilian bones have been obtained. They appear to be from 200 to 250 feet thick, and they pass beneath a peculiar cherty limestone which is sometimes called the "cherty rock of Stotfield"; this consists of an intimate mixture of calcareous and siliceous matter, and is said to be about 30 feet thick, but has yielded no fossils.[14]

On the coast of Sutherland, below Dunrobin Castle, a similar set of rocks is found, some 40 or 50 feet of yellowish sandstone dipping to the north-east and passing below a cherty rock exactly like that of Stotfield; this is succeeded by coarse sandstones with beds of conglomerate which contain many fragments of the cherty rock, but in spite of this evidence of erosion Professor Judd is inclined to regard them as Rhætic.

8. *Ireland*

Triassic rocks are only found in the north-eastern part of Ireland, and lie in an oval-shaped basin excavated out of the Palæozoic rocks, but only small tracts are exposed, the greater portion of the area being concealed by newer rocks.

A small outlying tract of Trias occurs near Kingscourt, County Cavan, about 30 miles south of the main outcrop in Tyrone; this is specially interesting, as proving that the Trias had formerly a southern extension in this direction.

On the borders of Tyrone and Armagh there are bright red sandstones belonging, it is supposed, to the Bunter, but no good sections are known. They pass eastward beneath the Tertiary basalt of Portadown.

The largest area of Trias occurs in the valley of the Lagan, and extends from Lurgan to Belfast, and thence along the northern shore of Belfast Lough as far as Black Head. The beds are also seen at intervals along the coast to the northward as far as Red Bay near Cushendall. They are thickest in the southern part of the area near Belfast. Rock salt is found at Carrickfergus, where the general succession is as follows:—

		Feet.
Keuper	Red marls with gypsum	700
	Rock salt and blue clays	150
	Brownish sandstones	perhaps 20
Bunter	Soft red and yellow sandstones with gray and buff shales	800

The sandstones have some resemblance to those of St. Bees in Cumberland, but it is not certain whether they should all be classed as Bunter, the upper part being possibly of Keuper age.

Rhætic Beds.—Where the Trias is covered by the Lias the intermediate zone of *Avicula contorta* is always found, and good sections are to be seen in Collin Glen near Belfast, Woodburn Glen near Carrickfergus, and Waterloo near Larne. Their maximum thickness is about 100 feet. At the base are gray clays surmounted by shales and sandstones with fish remains; the middle part consists of black shales with the usual fossils, and the upper beds are gray and brown shales with thin oolitic limestones.

Contemporaneous Volcanic Rocks

No volcanic rocks of undoubted Triassic age are known to occur in England or in Ireland, but in Scotland such rocks occur beneath the Triassic sediments of the Thornhill and Ayrshire

basins. These have been mentioned on p. 320, and their mode of occurrence is illustrated by Fig. 103.

The igneous zone consists of a number of lava-flows which mark successive eruptions, and have probably proceeded from more than one vent, for though they are all of a basic character they vary much in lithological composition. Some of them are basalts, and others are magnetite-felspar rocks, while the rock of Mauchline Hill is a picrite composed chiefly of olivine and augite. Magnetite is prevalent in all of them, and its oxidation has given them a red colour, on which account they have been described as "porphyrites."

Over these sheets of basic lava comes a group of stratified rocks, consisting essentially of the ordinary Triassic brick-red sandstone, but containing an abundant intermixture of volcanic material, either aggregated into lenticular seams, or scattered more or less abundantly through the body of the sandstone.

Besides these interbedded volcanic rocks there is other evidence of the number and activity of the volcanoes. Outside the existing tracts of Trias the Coal-measures are pierced by numerous large pipes filled with a coarse unstratified agglomerate, and usually appearing at the surface as small rounded hills or hillocks. Sometimes the agglomerate includes a core or column of lava, and the coal-seams in their neighbourhood are often charred or altered into columnar coke. There can be little doubt that these columns or necks are some of the vents through which the volcanic materials were ejected. The necks are especially numerous in the Dalmellington coal-field, but they occur also in Renfrewshire and Lanarkshire, piercing the highest Coal-measures in those counties.[15]

Physical Conditions of the British Region

That great physical changes took place in Northern Europe during the interval between the Permian and Triassic periods is shown by the great difference in the fauna and flora of the two periods. The Permian forms of life, which were survivals of the Carboniferous forms, were exterminated and replaced by a very different assemblage.

Again the unconformity which generally exists between the Permian and Trias, in Britain at any rate, points to a certain amount of elevation and to a considerable amount of surface change. The elevation may have led, in the first place, to the drying up or draining off of the Permian salt lakes, and it would seem that subsequent earth-movements produced some folding and ridging up of the crust along certain north and south lines which gave

rise to the formation of new water-basins. In these depressions the beds we know as Bunter were laid down, those of the British region being probably separated from those of Germany by one of the north and south ridges.

It would also appear that a further uplift of the Pennine range took place at this time, the Permian beds on each side receiving a slight outward tilting, so that the lower Triassic deposits were laid down across their edges, and doubtless in many places overstepped them on to the Carboniferous rocks. The Pennine range must have formed a much more lofty range of hills than it does now, and it is probable that most of its surface then consisted of the Millstone grit division, the erosion of which doubtless contributed much of the sand that enters into the composition of the Bunter sandstones and pebble beds.

Thus in early Triassic times there seem to have been three separate areas of deposition: one in the south over parts of Devon, Somerset, and Dorset, one in the north-west over the site of the western Permian basin, and one in the north-east, of which the eastern boundary is unknown.

Let us first consider the conditions which prevailed in the southern area during Bunter times. We find it bounded on the west and south by continuous and probably mountainous land extending from Wales, through Devon and Cornwall, to France and Belgium, the shores of the lake running across from South Devon toward, and perhaps into Normandy, where there is a small area of Trias, though it is doubtful whether any of it is of Bunter age. The Bristol Channel was a fiord narrowing westward instead of eastward, as now, and there were probably other similar inlets or fiords running westward into the Devonshire mountains. On the east and north this lake was bounded by land which stretched from Belgium through the east of England, and was united to Wales by an isthmus over the present counties of Worcester, Gloucester, and North Somerset, the Mendip Hills and the Clifton Downs being a part of this isthmus.

The pebble beds of Budleigh Salterton testify to the existence of strong currents or of torrential rivers, and the current-bedding indicates movement from the westward, but the assemblage of pebbles is not one which the neighbouring western areas could furnish, and as some similar rocks occur in Brittany, they may have come from the southward or the south-westward, possibly from land between France and Ireland which has long since been destroyed.

Passing now to the Midland and north-western area, we find the Bunter extending from the neighbourhood of Worcester and

Birmingham, through Staffordshire, Shropshire, Cheshire, and Lancashire, and bordering the coast of Cumberland in a manner which shows that it must underlie a considerable part of the sea between that coast and the Isle of Man. Thence it emerges again to the south of the Solway Firth and extends into the Carlisle basin. In all probability, also, it stretched some way inland from the head of Morecambe Bay, and may have been continuous with the strip which still remains in the valley of the Eden, so that the Lake District may have been an island in the great plain of the Bunter, which at its northern end seems to have held the waters of a salt lake for a time at any rate.

As the lower red gypsiferous marls of Cumberland do not occur to the south of Morecambe Bay there is no evidence that the southern part of the area above indicated was permanently filled with water during the Bunter epoch. In fact, there are strong reasons for believing the mass of the Bunter beds to be terrestrial deposits, partly of the nature of blown sand and partly of gravelly detritus, such as is brought down by rivers which only come into existence after periodical rains. In other words, it has been suggested that it is to the deserts of Central Asia and Arabia that we must look for deposits analogous to those of the Bunter.

We may just glance at the north-western area to note the disappearance of pebbles northward although the enveloping sandstone continues, and the nearly simultaneous incoming of saliferous marls at the base of the formation, facts which suggest the existence of a pebbly plain ending northward in a salt lake.

The pebble beds of the Midland area have given rise to much discussion, and several conflicting views as to the source of the pebbles have been put forward. The facts to be accounted for may be summarised as follows :—

(1) The pebbles are well rounded, like those of a sea-beach or such as have been carried for a long distance by a rapidly flowing river.

(2) The pebbles are largest in the more southern counties, and gradually diminish in size and in number northward.

(3) The pebble beds occur on both sides of the Pennine anticline, and pass northward into sandstone without pebbles.

(4) The commonest pebbles are those of rocks which can at present only be matched in Scotland and in Scotch conglomerates ; the common quartzites, the quartz-felspar grits, and some of the felstones, all resemble Scotch rocks more than any rocks now exposed in the Midlands or in Wales.

(5) There are, however, pebbles resembling those of Budleigh Salterton which contain fossils of the southern Devonian and Ordovician rocks.

Professor Bonney, relying on numbers 1 and 4, maintains that the pebbles have been brought by rivers from the north, but he is unable to give a satisfactory explanation of facts 2 and 3. He also fails to explain number 5.

Mr. W. J. Harrison argues from facts 2 and 3 that the pebbles must be of local origin, and have been derived from areas of Palæozoic rocks now concealed beneath the Neozoic strata of the Midlands; but this conflicts with the statement number 4, and fails to account for the rounding of the pebbles, unless they have been derived from a concealed Palæozoic conglomerate.

Thirdly, it has been suggested that the pebbles may have been carried northwards by a river flowing off the Palæozoic rocks which are known to occur in the south-east of England. This would satisfactorily explain numbers 1, 2, and 3, and is not inconsistent with number 5, but conflicts with number 4, for we have no ground for assuming that rocks of the special types mentioned occur in that district.

Thus no certainty has yet been arrived at, but for further information on the subject the reader is referred to Professor Bonney's latest paper (*Quart. Journ. Geol. Soc.* vol. lvi. p. 287), and to the author's *Building of the British Isles*, second edition (1892). It may be mentioned, however, that Professor Bonney's hypothesis requires three rivers to account for the disposition of the pebbles—two to bring the pebbles into Central England, and one to bring similar pebbles into Devon. Again, if a southern or south-western source can be claimed for the Devon pebbles, a similar source may be looked to for the Midland pebbles, though doubtless by a different route. Finally, rivers flowing from the southward would find natural debouchments in saline lakes at the northern end of the long Bunter plains after they had dropped their load of pebbles and sand, whereas rivers flowing from the northward could not possibly carry pebbles through such lakes if they were of a permanent nature. Moreover, the very existence of such lakes in the north argues a slope from south to north.

The break between the Bunter and the Keuper is most apparent in the Midlands, and is hardly traceable in the extreme north, nor is it very clearly marked in Devon. It presents, in fact, just such evidences of erosion as we might expect to find if tracts of dry sandy plain were converted into lakes by an increase in the rainfall of the surrounding districts, and there are two reasons for thinking that this formation of lakes was a consequence of subsidence: first, the subsidence indicated by the Muschelkalk of Germany must have brought the sea nearer Britain at the beginning of the Keuper epoch; secondly, the Keuper marls pass up gradually into a marine

deposit. Thus we may safely assume that the Keuper was formed during a time of slow general subsidence which ended in the submergence of all the lacustrine areas beneath the Rhætic sea.

During the formation of the Lower Keuper sandstones the south-western area still remained a separate basin, while the two northern tracts were united into one large lake which must have had somewhat the shape of an irregular horse-shoe. Later on, however, when several hundred feet of sandstone and marl had been deposited in both the northern and southern areas, the waters rose over the intervening barrier, and a large inland sea was formed which extended southward across the English Channel into the north of France.

The ripple-marks, sun-cracks, and reptile-tracks so frequent on the surface of the Keuper standstones show that the volume of the lake-waters was subject to variations, and that there were times when tracts of sand were exposed and dried in the sun, and on these the strange Amphibia of the period have left their footprints.

The epoch of the Rhætic shales, or *Avicula contorta* zone, marks the time when the depression had proceeded so far as to submerge the lowest tract of land which lay between the great salt lakes and the wide-spreading southern ocean. It is very probable that at this time the level of the water in the salt lakes had been greatly reduced by evaporation, and was perhaps many feet below that of the sea outside, so that when the dividing barrier was submerged the sea waters would rapidly invade the lake basins and fill them up to a common level.

Let us consider the nearly parallel case of the Caspian Sea at the present day. The level of this sea is 85 feet below that of the Black Sea, and it is surrounded by extensive low-lying areas which were formerly covered by its water before the sea shrank to its present dimensions. If, therefore, the waters of the Black Sea were to be admitted to the Caspian area through a general subsidence of the region they would rapidly raise the level of that sea by 85 feet, and in so doing would submerge a large part of Central Asia. Such a submergence would not only alter the conditions of aquatic life, but would completely change the climate of the whole region.

So when the Rhætic sea invaded the Triassic lakes, their scanty lacustrine fauna was extinguished and replaced by a new marine fauna, the climate of the surrounding country was changed, a fresh flora clothed the adjacent slopes, and the hum of insects filled the air. These are not mere imaginative assertions; we may take them as historic facts to be read from the actual Rhætic records. The bone beds testify to the suddenness of the invasion and to the inability of the Triassic fish to survive the change. The abundance

of small bivalve Mollusca shows that new species immediately made their way into the area from the sea, but did not find the conditions immediately suitable for vigorous growth. The plant and insect remains bear testimony to the alteration of the climate, the humidity of the air, and the general fertility of the surrounding region.

References

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[2] A good account of the German Trias will be found in Kayser and Lake's *Comparative Geology*.

[3] For accounts of the Devonshire Trias consult W. A. E. Ussher in *Quart. Journ. Geol. Soc.* vol. xxxii. p. 367, and vol. xxxiv. p. 49 ; Hull and Irving in *Quart. Journ. Geol. Soc.* vol. xlviii. pp. 60 and 68 ; and T. G. Bonney in *Geol. Mag.* ser. 4, vol. ii. p. 79.

[4] See the "Triassic and Permian Rocks of the Midland Counties of England," by E. Hull, *Mem. Geol. Survey* (1869), and "Geology of the Birmingham District, by C. Lapworth, in *Proc. Geol. Assoc.* vol. xv. p. 377 (1898).

[4a] "Geology of the Birmingham District," *Proc. Geol. Assoc.* vol. xv. p. 384.

[5] "Geology of Nottingham," by J. Shipman, in *Proc. Nott. Nat. Hist. Soc. for 1889.*

[6] See Messrs. Wilson and Quilter in *Geol. Mag.* Dec. 3, vol. i. p. 416.

[7] See G. H. Morton in *Geol. Mag.* Dec. 3, vol. vii. p. 497, and his *Geology of the Country round Liverpool*, second edition (1896) ; also the "Geology of Chester" and "Geology of Prescot," by A. Strahan, *Mem. Geol. Survey* (1881).

[8] See G. Maw in *Geol. Mag.* Dec. 1, vol. vii. p. 203 (1870).

[9] See J. G. Goodchild in *Geol. Mag.* Dec. 3, vol. ix. p. 564 (1892).

[10] See Harkness in *Quart. Journ. Geol. Soc.* vol. vi. p. 389, and vol. xii. p. 254.

[11] See *Quart. Journ. Geol. Soc.* vol. lvii. p. 226 (1901).

[12] See J. W. Judd, *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 686 (1878).

[13] E. T. Newton in *Phil. Trans. Roy. Soc.* vol. clxxxiv. p. 431 and plates (1893), and *Geol. Mag.* Dec. 3, vol. x. p. 555.

[14] J. W. Judd, *Quart. Journ. Geol. Soc.* vol. xxix. p. 128 (1873), and *Proc. Roy. Soc. for 1885*, p. 394.

[15] See *Explanations of Geol. Survey of Scotland*, sheets 9, 14, and 22. Also the *Ancient Volcanoes of Great Britain*, by Sir A. Geikie, under the head of Permian Volcanoes.

CHAPTER XIV

THE JURASSIC SYSTEM

Nomenclature and Divisions

From the prevalence of oolitic limestones in the central part of this system in England it was termed the Oolitic series (by Conybeare and Phillips in 1822); subsequently the Lias was described as separate from the Oolites, and the two together were termed the *Jurassic System*, that name being used on the Continent for the equivalent rocks which form the Jura Mountains between France and Switzerland.

The division into Lias and Oolites is an unequal one, and a more natural arrangement divides the whole Jurassic system into three great series—a Lower, Middle, and Upper. This arrangement will be adopted in the following pages, and the minor groups which constitute the three great divisions of the Jurassic system are given below, with the average thickness of each series in the south of England :—

		Average Thickness.
Upper Jurassic Series	Purbeckian Portlandian Kimeridgian Corallian Oxfordian	2000 feet.
Middle Jurassic Series	Great Oolite (Bathonian) Inferior Oolite (Bajocian)	800 feet.
Lower Jurassic Series	Upper Lias Middle Lias Lower Lias	900 feet.

The Lias is essentially a clay formation, with occasional bands of limestone and ironstone of variable thickness.

The Middle Jurassic series consists mainly of limestones, with only subordinate bands of clay.

The Upper Jurassic, again, is an argillaceous series, the limestones being discontinuous and sometimes absent or replaced by clays.

The most persistent formations are the three great clays: the Lower Lias, the Oxford, and the Kimeridge clay. These range all across England, and form broad tracts of low-lying land, while the intermediate limestones, where they are well developed, form long ridges, with escarpments facing the west or north-west, in consequence of the prevalent easterly dip (see Figs. 64 and 65).

It was long ago remarked by Dr. Buckland, that a line drawn through England from the mouth of the Tees to the coast of Dorset, and corresponding with the base-line of the Jurassic system, would divide the country into two totally dissimilar parts, contrasting strongly with each other, both in their physical and economical aspects. The country to the north-west of this line is chiefly composed of Palæozoic rocks, which often rise into barren mountainous tracts, but which in many places contain valuable minerals, such as coal, iron, lead, copper, and tin. The country to the south-east of the line is entirely Neozoic ground, the greater part of which has a fertile soil, but little subterranean wealth, and few parts of which rise to an elevation of 900 feet. The first-mentioned part of the country is largely inhabited by a mining and manufacturing population, while the inhabitants of the south-eastern districts are chiefly employed in agricultural pursuits.

Life of the Period

The rate of change in the organic world and the differentiation of species appears to have become much more rapid in Jurassic times than it had been in Palæozoic times, so that any given group of species has a much less vertical range, and consequently a much smaller set of strata requires separate description. It will, therefore, be convenient to consider each of the three major divisions of the system separately.

With respect to the life of the period the prevalent genera and the characteristic species of each division will be treated separately, but it will be convenient here to point out the distinguishing features of the Jurassic fauna as a whole.

In the first place, it was an "*age of Reptiles*," and it is specially characterised by the remarkable development of the orders *Dinosauria*, *Pterosauria*, *Ichthyopterygia*, and *Sauropterygia*. These orders survived into the Cretaceous period and then became extinct. The *Dinosauria* were land animals, and many were of gigantic size (from 20 to 40 feet long); in most cases their hind limbs are much

longer and stronger than the fore legs, so that they could walk in an upright position like a kangaroo. Some were carnivorous (as *Megalosaurus*) and some herbivorous (as *Cetiosaurus*). The *Pterosauria* are Reptiles adapted for the purpose of flight in the air, and thus possess many bird-like characters, such as pneumatic bones, keeled sternum, and more or less bird-like skull; their membranous wings were attached to the sides of the body and the greatly elongated fifth digit. The other two orders were specially adapted for life in the sea, both pairs of limbs being modified into the form of paddles or flippers. Representatives of the orders *Crocodilia* and *Chelonia* also occur.

True *Birds* also make their appearance, but are known by two specimens only, found at Solenhofen in Bavaria. They are referred to the genus *Archæopteryx*, which exhibits strong Reptilian affinities, possessing teeth and a long narrow tail of twenty separate vertebræ, each of which apparently carried a pair of feathers; the wings are bird-like, and the creature was about the size of a common pigeon.

Remains of Mammalia have been found at two horizons, in the Stonesfield slate (Bathonian) and in the Purbeck beds. One genus (*Plagiaulax*) belongs to the Prototheria, the rest to the Marsupalia, which class now appears for the first time. Of Marsupials the Stonesfield slate has yielded five, and the Purbeck beds ten genera.

Another special feature of the fauna is the great abundance and variety of the Ammonoid Cephalopoda. A few genera such as *Phylloceras* appeared in Triassic times, but a large number appear in Jurassic rocks, and many are confined to the period. The genus *Nautilus*, which also dates from the Triassic period, is the only representative of the Palæozoic Nautiloidea. *Belemnites*, a genus of Dibranchiate Cephalopods, appears in the Lias and reaches its maximum development in Jurassic times.

Among Lamellibranchia the Ostreidæ and Pectinidæ become abundant, and the genus *Gryphæa* is very characteristic of the period; *Trigonia* also is abundant.

Among Echinoderms the true Echinids (Euechinoidea) make their appearance in England, and are very abundant both in species and individuals. Corals also abound in most of the limestones.

Plants occur at several horizons, and Cycadaceæ are so abundant that botanists have called the Jurassic period the "age of Cycads." The chief genera are *Zamites*, *Otozamites*, *Mantellia*, *Nilssonia*, *Pterophyllum*, and *Williamsonia*. Ferns continue to be common, and conifers were represented by genera allied to the modern *Araucaria*, cypress, and yew.

A. The Lias or Lower Jurassic Series

Subdivisions.—This series has on the whole a very uniform lithological aspect throughout England. It consists almost everywhere of four successive sets of strata, and might with good reason be divided into four stages instead of the three which are usually adopted in England, for such a subdivision is not inconsistent with the range of the fossils, and is actually in use on the Continent (see table below). Thus (1) its lowest beds are more or less calcareous, and consist generally of thin-bedded limestones and shaly clays; (2) above these comes a thick mass of dark gray clays; (3) these are succeeded by sandy clays and sandy limestone (marlstone); (4) while at the top are thin limestones and marly clays.

A further subdivision of the Lias into zones has resulted from a careful study of the distribution of its fossils. These zones are each characterised by one or more species of Ammonites, and though some of them are more or less local, and cannot be traced all across England, they can be grouped into nine principal zones which are so traceable. The following table shows the divisions in general use, the principal zones, and the continental divisions:—

	Lithology.	Zones.	Cont. Equiv.
Upper Lias	Clays and thin limestones	Z. of Am. communis ,, ,. serpentinus	Toarcien.
Middle Lias	Marlstones, sands, and sandy clays	,, ,, spinatus ,, ,, margaritatus	Pliensbachien. or Charmouthien.
Lower Lias	Clays . .	,, ,, capricornus ,, ,, Jamesoni ,, ,, oxynotus	Sinemurien.
	Limestones and clays	,, ,, Bucklandi ,, ,, planorbis	Hettangien.

Lower Jurassic Life

The reader may be reminded that throughout Triassic times our islands formed part of a continent which occupied the northern part of Europe, and some part at least of the North Atlantic region, and that it was not until the Rhætic epoch that the inland lakes of this continent were submerged beneath the waters of an open sea. Further, the fauna of the British Rhætic beds or zone of *Avicula contorta* contains but a small number of species, and it was not till the time of the Lias that conditions were favourable for the establishment of a new and abundant marine fauna in the British region. We are thus suddenly presented with an assemblage of fossils which is very different from those of the Carboniferous and Permian periods, and for the ancestors of which we must search the marine Trias of Southern and Central Europe.

The following are some of the genera which are not known in Britain before the age of the Lias, though some occur in the Alpine Trias. Those preceded by an asterisk did not survive the Jurassic period.

Anthozoa.—Astrocœnia, *Cyathocœnia, *Heterastrea, Isastrea, Montlivalta, *Stylastrea, Thamnastrea, Thecosmilia, Trochocyathus.

Echinoderma.—*Pentacrinus, Isocrinus, Ophioderma, Ophiolepis, Acrosalenia, Cidaris, Rhabdocidaris, Hemipedina, Pseudodiadema.

Crustacea.—*Æger, *Eryma, Eryon, Glyphæa, *Penæus, *Scapheus.

Brachiopoda.—Waldheimia, Thecidium.

Lamellibranchia.—Astarte, *Cardinia, Cardita, *Ceromya, Corbula, Cucullæa, Trapezium, Exogyra, Goniomya, *Gresslya, Gryphæa, Velopecten, *Hippopodium, Homomya, Inoceramus, Macrodon, Myoconcha, Opis, Ostrea, Perna, Pinna, Pholadomya, Pleuromya, *Tancredia, Thracia, Trigonia, Unicardium.

Gastropoda. — *Alaria, Actæonina, Amberleya, Cerithium, *Ceritella, *Cryptænia, Cylindrites, *Exelissa, Littorina, Monodonta, Nerita, Neritopsis, Patella, Pseudomelania, *Purpurina, Solarium, *Trochotoma, Turritella.

Cephalopoda. — *Ægoceras, Amaltheus, Ancyloceras, *Arietites, *Cœloceras, *Dactylioceras, *Deroceras, Harpoceras, *Haugia, *Hildoceras, *Grammoceras, Lytoceras, *Ophioceras, *Phylloceras, *Psiloceras, *Schlotheimia, *Stephanoceras, Belemnites.

Pisces.—Acrodus, *Dapedius, *Eugnathus, Hybodus, Lepidotus, *Leptolepis, *Pholidophorus.

Reptilia.—*Dimorphodon (a Pterodactyle), *Scelidosaurus (a Dinosaur), *Steneosaurus and *Pelagosaurus (Crocodiles), *Thaumatosaurus, Ichthyosaurus, Plesiosaurus, and Eretmosaurus (the last three, however, are represented in the Rhætic bone beds).

Fossils of the Lower Lias

Actinozoa. Montlivaltia rugosa, Heterastrea Tomesi.

Echinoderma. Pentacrinus briareus, Isocrinus basaltiformis, Cidaris Edwardsi.

Brachiopoda. Spiriferina Walcotti, Rhynchonella variabilis, R. rimosa, Waldheimia numismalis.

Lamellibranchia. Avicula cygnipes, Cardinia Listeri, Gryphæa arcuata (=incurva), Hippopodium ponderosum, Lima gigantea, Avicula (Pseudomonotis) decussata, Ostrea liassica.

Gastropoda. Pleurotomaria anglica, Cryptænia expansa, Amberleya elegans.

Cephalopoda. The following Ammonites characterise zones or subzones in ascending order, Am. (Psiloceras) planorbis, Am. (Schlotheimia) angulatus, Am. (Arietites) Bucklandi,

Am. (Arietites) semicostatus, Am. (Arietites) Turneri, Am. (Arietites) obtusus, Am. (Oxynoticeras) oxynotus, Am. (Ophioceras) raricostatus, Am. (Deroceras) armatus, Am. (Ægoceras) Jamesoni, Am. (Amaltheus) ibex, Am. (Ægoceras) capricornus. Belemnites acutus, B. elongatus, B. clavatus, Nautilus striatus.

Pisces. Dapedius punctatus, Hybodus reticulatus, Acrodus Anningæ.

Reptilia. Ichthyosaurus communis, Plesiosaurus dolichodeirus.

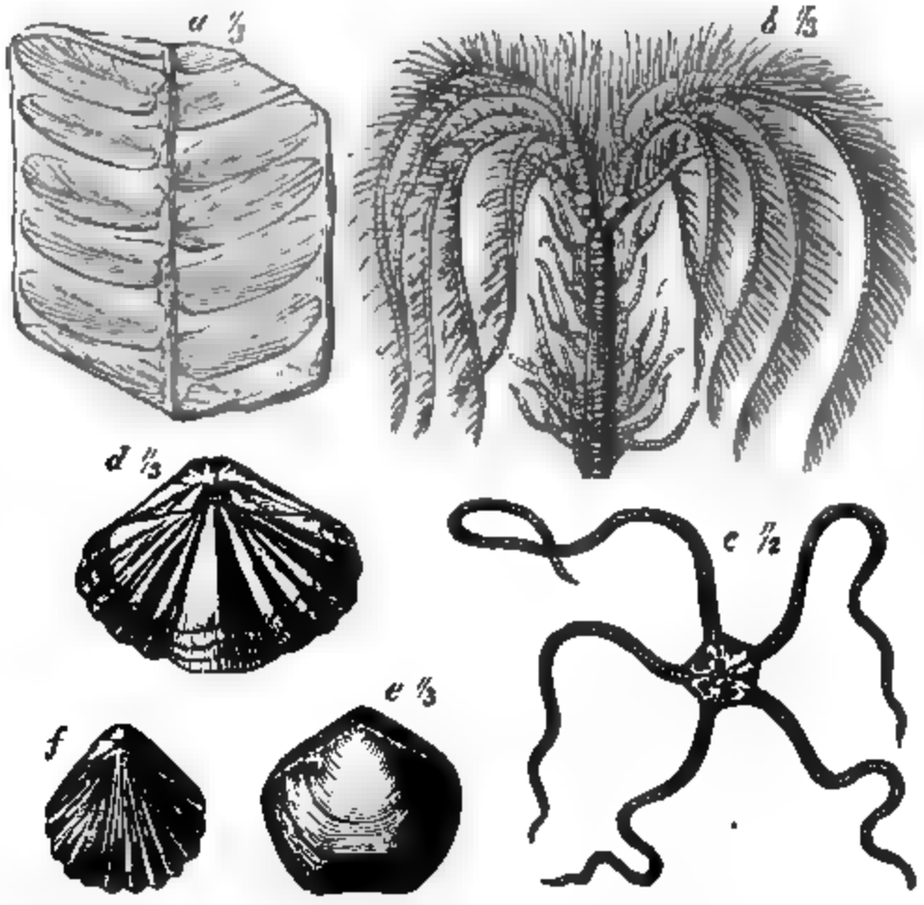

Fig. 104.—GROUP OF LIASSIC FOSSILS.

a. Otopteris obtusa.
b. Pentacrinus briareus.
c. Ophioderma Egertoni.
d. Spiriferina Walcotti.
e. Waldheimia numismalis.
f. Rhynchonella rimosa.

Fossils of the Middle Lias

Echinoderma. Ophioderma Egertoni, O. Millen.

Brachiopoda. Rhynchonella tetrahedra, R. acuta, Terebratula punctata, Waldheimia resupinata.

Lamellibranchia. Avicula inæquivalvis, Cardium (Protocardia) truncatum, Gresslya intermedia, Lima punctata, Modiola scalprum.

Gastropoda. Trochus lineatus.

Cephalopoda. **Am. (Amaltheus) margaritatus, Am. (Amaltheus) spinatus, Am. (Lytoceras) fimbriatus, Belemnites paxillosus.**
Reptilia. **Thaumatosaurus propinquus.**

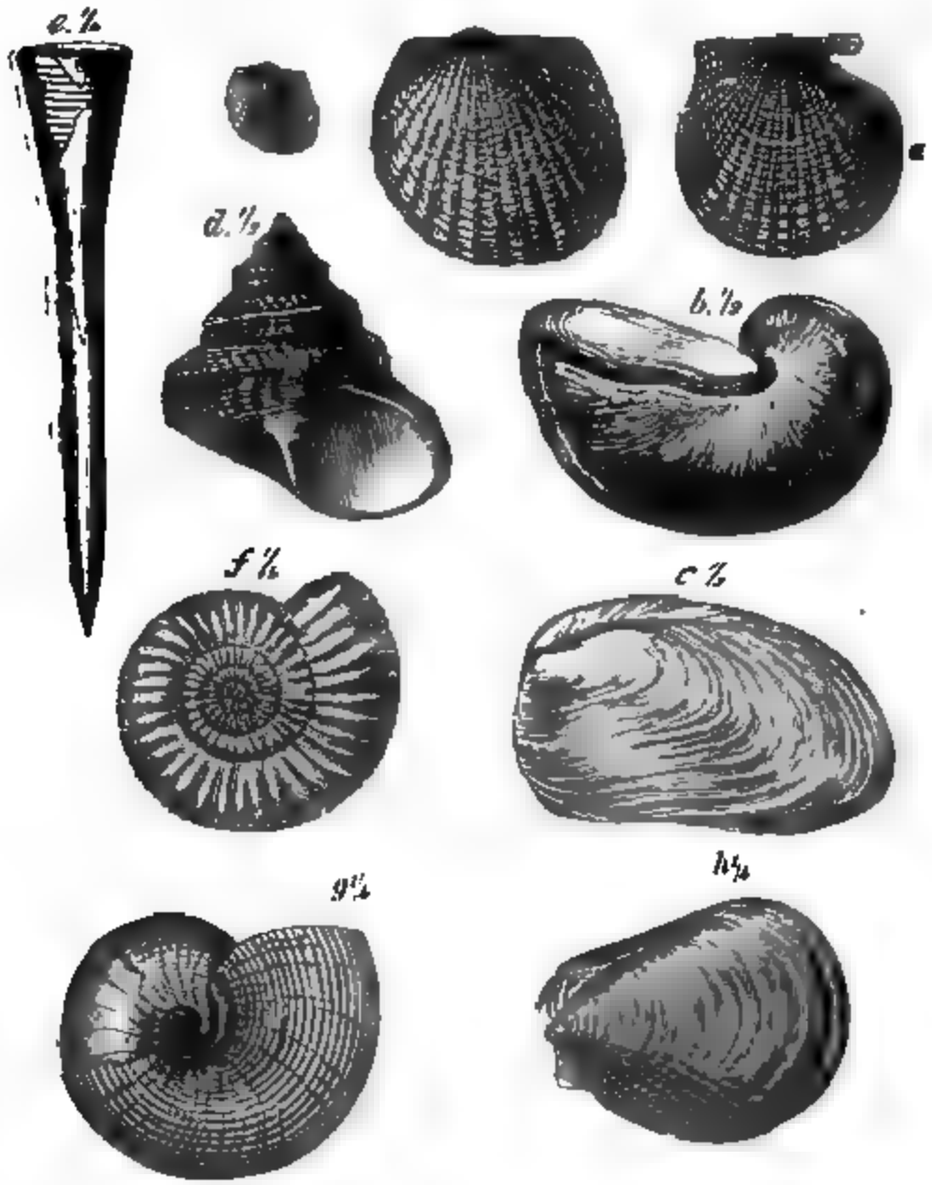

Fig. 105.—GROUP OF LIASSIC FOSSILS.

a. Pseudomonotis decussata.
b. Gryphæa arcuata.
c. Hippopodium ponderosum
d. Pleurotomaria anglica.
e. Belemnites elongatus.
f Ammonites communis.
g. Nautilus striatus.
h. Lima gigantea.

Fossils of the Upper Lias

Echinoderma. **Pentacrinus jurensis.**
Brachiopoda. **Rhynchonella jurensis, Waldheimia Lycetti, Discina reflexa,** Leptæna Moorei.

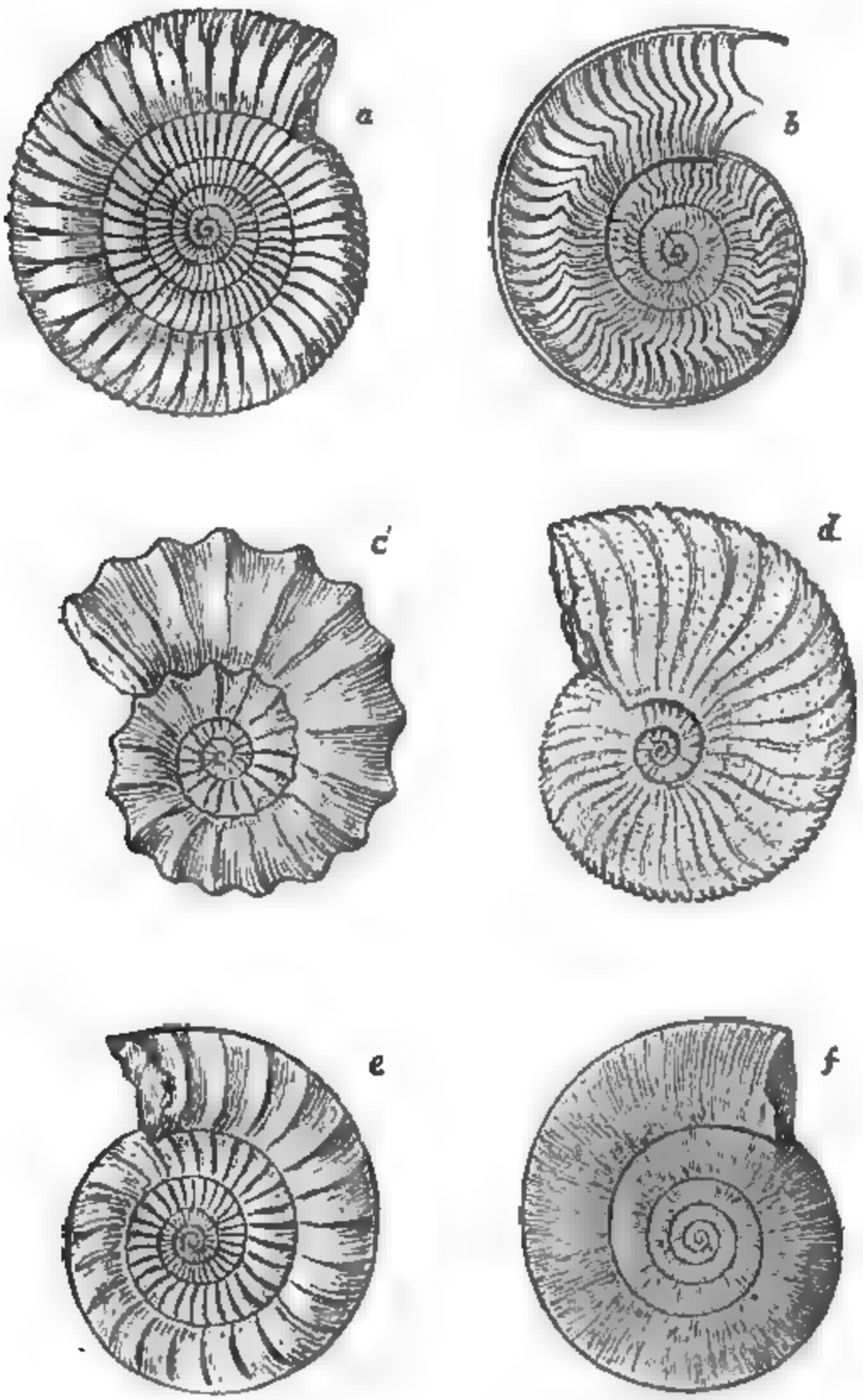

Fig. 106. —LIASSIC AMMONITES.

a. Ammonites communis (½).
b. Ammonites serpentinus (½).
c. Ammonites capricornus (¹).
d. Ammonites margaritatus (½).
e. Ammonites Bucklandi (½).
f. Ammonites planorbis (½).

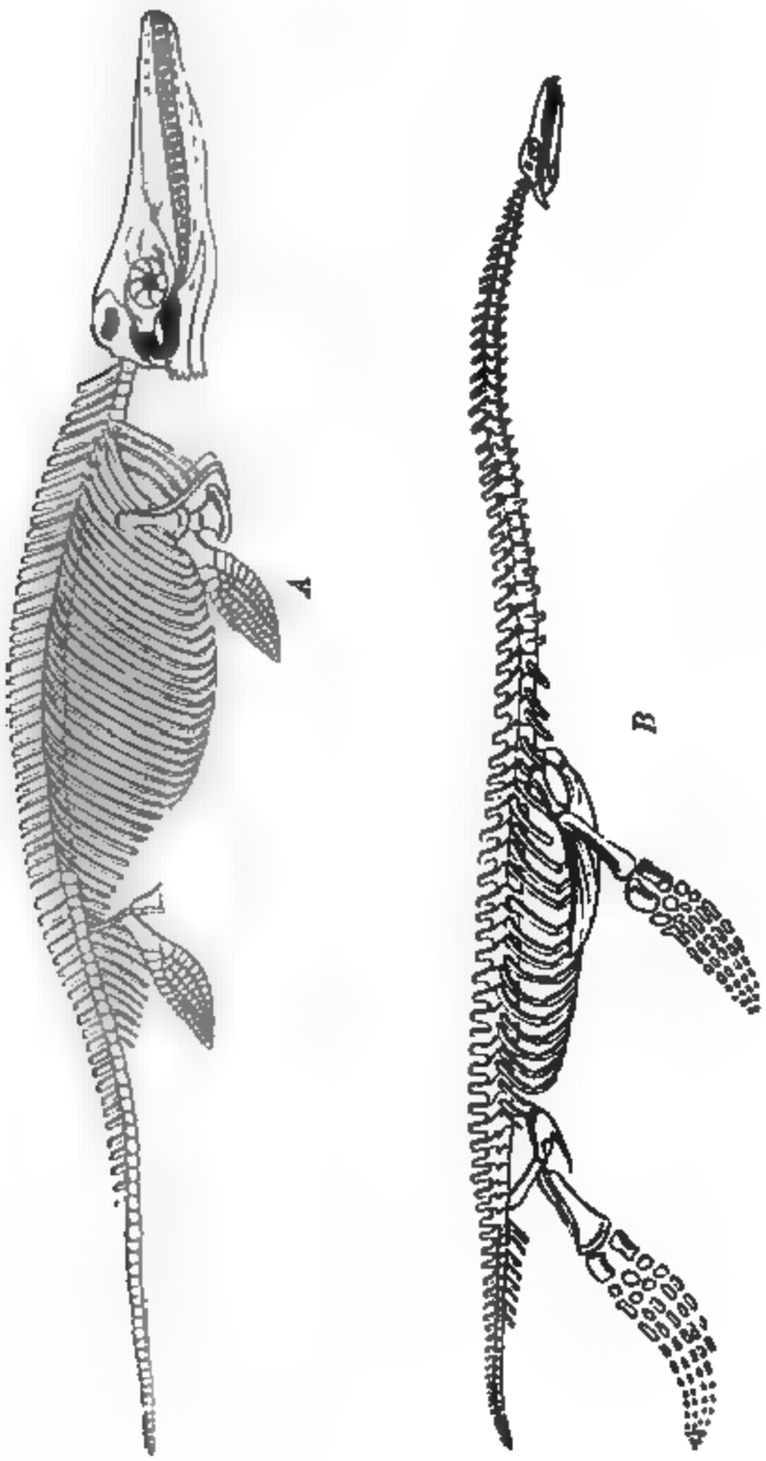

Fig. 107.—TWO MARINE REPTILES FROM THE LOWER LIAS.

A. Ichthyosaurus communis. *B*. Plesiosaurus dolichodeirus.

Lamellibranchia. Inoceramus dubius, Gresslya donaciformis, Nuculana ovum, Pecten pumilus, Posidonomya Bronni.
Gastropoda. Trochus lineatus.
Cephalopoda. Am. (Dactylioceras) annulatus, Am. (Harpoceras) serpentinus, Am. (Dactylioceras) communis, Am. (Hildoceras) bifrons, Belemnites abbreviatus, B. Voltzii.
Pisces. Lepidotus elvensis (=gigas), Leptolepis concentricus.
Reptilia. Ichthyosaurus acutirostris, Steneosaurus Chapmanni.

Stratigraphy

The Lias occupies the coast of Dorset from Lyme Regis to Bridport harbour, it stretches inland to Ilminster, Petherton, and Yeovil, and thence passes northward to the Mendip Hills, where all the divisions become very thin. North of Bristol it thickens again and forms a broad tract running through the counties of Gloucester, Warwick, Northampton, Leicester, Lincoln, and York. Another fine coast section is exposed in the cliffs of the Yorkshire coast between Redcar and Whitby.

Outlying tracts of Lias occur in Staffordshire, at Needwood Forest, and north of Abbots Bromley; in Shropshire, between Wem and Audlem, and in Cumberland, near Carlisle, proving that the formation originally extended far to the north-west of its main line of outcrop. There is little doubt, indeed, that the Lias was once co-extensive with the Trias, but there is no indication that it ever extended very far beyond the limits of the Keuper marls.

In Scotland remnants of Lias occur above the Trias on the west coast, and it is also found on the east coast of Sutherland.

In Ireland Liassic rocks crop out in certain places from beneath the Cretaceous rocks of Antrim, but only Lower Lias is found, the higher beds having been removed before the deposition of the Cretaceous rocks.

With regard to the eastward subterranean extension of the Lias in England it is known that its upper beds, as they pass beneath the higher members of the Jurassic system, thin very rapidly. Thus in a boring at Burford, in Oxfordshire, the Middle and Upper Lias are together less than 30 feet thick; the Lower Lias is there about 620 feet thick, and the Rhætic is 10 or 12 feet; but between that place and Richmond the Lias has wholly disappeared, allowing rocks of the Middle Jurassic series to rest directly on rocks which are either of Triassic or of Old Red Sandstone age. It would appear, therefore, that between Richmond and the Malvern Hills the width of ground now occupied by the Lias is less than 100 miles. No trace of Lias has been found in any of the deep borings that have been made in the eastern counties. Northward it may underlie part of Cambridgeshire, but it thins out beneath Suffolk,

for a boring at Culford, near Bury St. Edmunds, proved the Lower Cretaceous beds to rest directly on Palæozoic rocks.

The chief zonal and provincial features of the English Lias may be indicated by the description of five special districts: (1) Dorset, (2) Somerset and Gloucester, (3) Warwickshire and Northamptonshire, (4) Lincolnshire, (5) Yorkshire.

1. *Dorset Coast*

Lower Lias.—The succession of beds which constitute the Lower Lias at Lyme Regis is as follows in descending order :—

		Feet.
Green Ammonite beds	Bluish gray marly clays with *Am. Loscombei*	105
	Bluish gray marly clays with *Am. latæcosta*	
Belemnite beds	Pale gray marls with some marly limestones; few fossils	80
Black shales	Shaly marls with *Am. raricostatus*	15
	Shaly marls with *Am. oxynotus*	15
	Dark gray shales and limestones with *Am. obtusus* and *Am. Brookei*	170
Blue Lias	Shales and marls with *Am. semicostatus*	19
	Limestones and shaly clays with *Am. Bucklandi* and *Am. angulatus*	64
	Limestones with *Am. planorbis* and *Ostrea liassica*	22
		490

The succession of zones and subzones is normal up to that of *Am. raricostatus*, but above that the typical Ammonites are rare. The Belemnite beds are supposed to represent the *armatus*, *Jamesoni*, and *ibex* zones, but the two latter species of Ammonites do not occur. The succeeding beds may be regarded as the equivalent of the zone of *Am. capricornus*, and its subzone of *Am. Henleyi*.

Middle Lias.—This division is exposed in the cliffs between Charmouth and Bridport, and presents the following succession :—

		Feet.
Zone of *Am. spinatus*	Ferruginous limestone (marlstone)	1
	Yellow sands and sandy clays	77
Zone of *Am. margaritatus*	Laminated micaceous sands and clays	72
	Blue micaceous clays with limestone nodules	160
	"Three tiers" of calcareous flagstone with sandy clays between	35
		345

The blue clays contain *Am. margaritatus*, *Bel. elongatus*, *Plicatula spinosa*, etc., and at their summit is a bed of Calcareous sandstone known as the Starfish beds, from its having yielded two species of *Ophioderma*. The Marlstone is here a very thin bed.

Upper Lias.—This can be seen in Westcliff, south of Bridport, and in some of the lanes north of that town. Its basement bed is a whitish argillaceous limestone (1½ to 2½ feet thick), which is welded on to the top of the marlstone, but contains a very different set of fossils, including the Ammonites *serpentinus*, *annulatus*, and *communis*. Above this limestone are about 70 feet of gray sandy shales, which merge upward into the Midford Sands and contain very few fossils, but *Am. radians* has been found in their highest part, which may therefore belong to the zone of *Am. jurensis*.

2. *Somerset, Gloucester, and Glamorgan*

Lower Lias.—In Somerset the beds forming the Lower Lias are similar to those of the Dorset coast, but the higher zones are seldom exposed. The limestones of the lower zones have been quarried at many places from Ilminster eastward, and are upwards of 200 feet thick, about half of this belonging to the zone of *Am. planorbis*, and the rest to those of *Am. angulatus* and *Am. Bucklandi*. The quarries at Queen Camel and Street have yielded many fine specimens of *Ichthyosaurus*, *Plesiosaurus*, fish, and other fossils, and at the base are shaly limestones which contain remains of insects and Decapod Crustacea (*Eryon*).

Evidence that the higher zones persist is found in the occurrence of *Am. semicostatus*, *obtusus*, and *oxynotus*, but it is doubtful if the Lower Lias is more than 400 feet thick.

Westward it extends to the coast near Watchet, where the zones of *Am. planorbis*, *angulatus*, *Bucklandi*, and *semicostatus* can be recognised, and have a thickness of about 150 feet.

Northwards, however, there is a rapid thinning, so that at Shepton Mallet the same four zones have a thickness of only 33 feet, overlain by 36 feet of clays and limestones referable to the *obtusus* and *oxynotus* zones. Round the Mendip Hills there are only irregular patches of limestone and clay to represent the whole of the Lower Lias. To the north of the Mendips, however, it soon regains its normal aspect and thickness.

Westward, in South Wales, there are fine exposures of the lower beds in the cliffs between Penarth and Dunraven Castle. At Penarth there is a normal sequence of limestones and clays for 135 feet, but when followed westward they exhibit a remarkable lithological change. At Sutton and Brocastle, near Bridgend (Glamorgan), they consist of massive limestones, conglomeratic at the base, resting either on the Rhætic sands or on the Carboniferous limestone. Corals of the genera *Astrocœnia*, *Montlivaltia*, and *Thecosmilia* are predominant in the basement beds, together with

Pseudomonotis fallax and *Ostrea liassica*. The higher beds contain *Ammonites angulatus* and *Littorina clathrata*.[1]

Middle Lias.—The best locality in Somerset for studying this division is near Glastonbury, where the succession, according to Mr. H. B. Woodward, is as follows :—

	Feet.
3. Rock-bed (Marlstone)	up to 2
2. Micaceous sandy clays and sands	70
1. Micaceous shales	140

Round the Mendip Hills the Middle Lias becomes very attenuated, and is represented sometimes by a few feet of marly shale, and sometimes by conglomerate resting directly on Carboniferous limestone; in other places it is overlapped by the Inferior Oolite.

Towards Bath the normal succession is again found, but with a thickness of only 50 or 60 feet. Northwards through Gloucestershire the beds thicken considerably, till near Stinchcombe the marlstone is 15 feet, and the underlying sands and clays are about 150. The Marlstone here forms a conspicuous rock-bed which is often quarried. It contains *Am. spinatus*, *Bel. paxillosus*, *Rhyn. tetrahedra*, *Pecten æquivalvis*, and other fossils.

Upper Lias.—In Somerset this consists of pale-coloured limestones and marls at the base, surmounted by a variable thickness of blue and brown clay (40 to 70 feet). In some places a layer of brown shaly clay separates the marlstone from the Upper Lias limestone, and this clay contains many small brachiopods, such as *Leptæna Moorei*, *L. Bouchardi*, *Thecidium rusticum*, *Spiriferina ilminsterensis*, and *Zellania liassica*. The limestone contains the usual Ammonites as well as Reptilia, Fish, Crustacea, and Insects. The succession in Gloucester is similar, and the quarries near Dumbleton have yielded many fish and insects.

3. *The Midlands*

Lower Lias.—Good sections of several parts of the Lower Lias are to be found near Harbury and Fenny Compton in Warwickshire, where the succession appears to be as follows :—

7. Clay with *Am. capricornus* at Southam.
6. Clay and bed of shelly limestone, *Am. Loscombei*.
5. Clays with limestone nodules, *Am. ibex*, *Am. Henleyi*.
4. Clays with limestone bands, *Am. Jamesoni*, *Am. armatus*.
3. Zone of *Am. oxynotus*—not exposed.
2. Limestones and clays with *Am. Bucklandi* and *Am. angulatus*.
1. Blue clays and shales = zone of *Am. planorbis*.

The total thickness is estimated at about 460 feet.

Middle Lias.—The best known and most fully explored sections of this division are near Banbury, Deddington, and Hornton, but its thickness seems to be less than 150 feet. Mr. H. B. Woodward[1a] remarks that "the Marlstone Rock-bed is perhaps nowhere better developed than in the country around Banbury. It covers an extensive area to the north-west, forming a plateau that rises gradually from about 500 feet at Banbury to the escarpment of Edge Hill, 710 feet high, and this area is intersected by several deep valleys." The marlstone consists of more or less ferruginous and sandy limestone, which varies from 12 to 25 feet in thickness. The outer parts are always brown from the oxidation of the iron, but the centres of large blocks are generally gray. The commonest fossils are *Terebratula punctata* and *Rhynchonella tetrahedra*, which often occur in clusters.

Below the Marlstone are sandy micaceous clays with *Am. margaritatus* and *Belemnites* of several species. These beds are from 100 to 120 feet thick.

Upper Lias.—In Northamptonshire this has been divided as follows:—

		Feet.
Zone of *Am. communis*	Clays with *Nuculana ovum*	about 50
	Clays with few fossils	68 to 90
	Clays with *Am. communis*	2 to 8
Zone of *Am. serpentinus*	*Serpentinus* beds	3 to 5
	Paper shale and insect limestone	1 to 2
		Up to 155

The "insect limestone," though a thin bed, yields many fossils, especially insects and remains of fish as well as Ammonites. The *serpentinus* beds consist of marl with a limestone containing several species of Ammonites, and though *Am. serpentinus* is commoner than *Am. communis* in these beds, both range up to the lower *Nuculana ovum* beds, but they do not occur in the highest *Nuculana ovum* clays, which contain *Am. Lilli* and *Am. lympharum* with some other shells characteristic of the *Am. jurensis* zone.

4. *Leicester, Rutland, and Lincoln*

In these counties we find the following zones:—

Upper Lias	Clays with *Am. bifrons* and *Nuculana ovum*. Clays with *Am. communis*. Clays with *Am. serpentinus*. Shales with fish and insect limestones.
Middle Lias	Marlstone Rock-bed (*Am. spinatus*). Blue micaceous clays with septaria and bands of sandy ironstone (*Am. margaritatus*).

Lower Lias, B	Blue clays with septaria (*Am. capricornus*). Blue clays with thin limestones and septaria (*Am. ibex* and *Am. Jamesoni*). Sandy clays and sands, occasionally indurated into a stone (*Am. armatus*). Blue clays with small septaria (*Am. oxynotus*).
Lower Lias, A	Ferruginous limestones with *Am. semicostatus*. Blue clays and gray limestones (*Am. Bucklandi*). Dark blue pyritous clays (*Am. angulatus*). Limestone and shales (*Am. planorbis*).

Lower Lias.—The zones of *Am. planorbis*, *Am. angulatus*, and *Am. Bucklandi* present the same features as elsewhere, and have a combined thickness of about 200 feet. They are succeeded by several beds of hard ferruginous limestone with interbedded shales (the *Am. semicostatus* zone), which thicken northward till they are 27 feet thick at Scunthorpe and Frodingham, where they are worked for ironstone.[1]

The upper part (B) of the Lower Lias is about 470 feet thick in the Vale of Belvoir, and a boring at Grantham showed the Lower Lias as a whole to be about 700 feet thick. The *obtusus* zone is thin or absent, but clays with *A. oxynotus* and *A. raricostatus* occur, and are about 90 feet thick. Northwards, however, the thickness diminishes. The lower zones (A) maintain their thickness, but the zones of *oxynotus*, *armatus*, and *Jamesoni* are represented by clays from 100 to 140 feet thick, surmounted by a bed of ironstone about 4 feet thick, which is known as the "Pecten bed," from the abundance of several species of *Pecten*. This bed contains a mixture of Lower and Middle Lias species, and is by some regarded as the base of the Middle Lias, but its Ammonites are *armatus*, *Henleyi*, and *striatus*, while the clays above it contain *Am. capricornus* throughout, and not *margaritatus*. These clays are about 70 feet thick, and consequently the total thickness of Lower Lias in this district is from 400 to 440 feet.

Middle Lias.—In Rutland and along the Vale of Belvoir the Middle Lias presents its usual zonal subdivisions, and maintains a thickness of about 150 feet. The Marlstone is from 25 to 30, and forms a bold escarpment which overlooks the plain of the Lower Lias from Ashwell by Holwell, Belvoir, and Grantham, near which places it has been largely worked for ironstone. The clays below generally contain *Am. margaritatus*, *Protocardia truncata*, and *Modiola scalprum* in abundance. These clays have been traced northward to Lincoln, where they pass down into clays with *Am. capricornus*, but farther north the *margaritatus* zone appears to die out, and the *capricornus* clays are succeeded directly by the marlstone, which in North Lincolnshire is only from 7 to 10 feet in thickness.

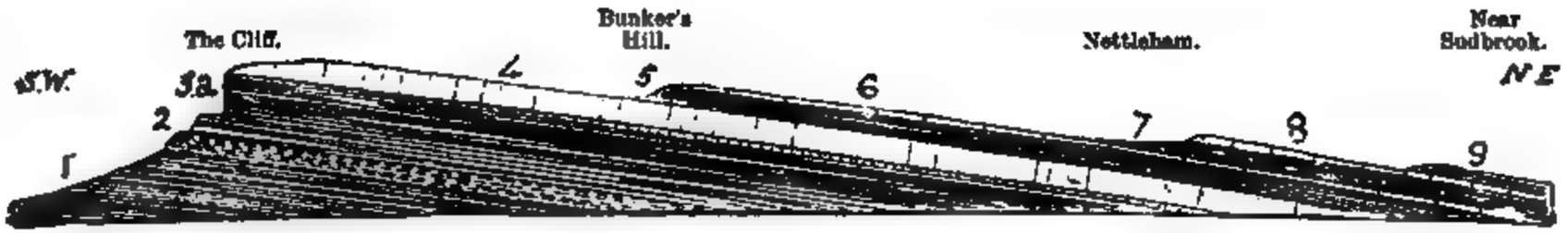

Fig. 108.—SECTION THROUGH THE JURASSIC SYSTEM NEAR LINCOLN (by W. D. Carr.) Distance about 5 miles.

9. Oxford Clay.
8. Cornbrash.
7. Great Oolite Clay.
6. Great Oolite Limestone.
5. Upper Estuarine Clays.
4. Lincolnshire Limestone.
3. Upper Lias.
2. Middle Lias
1. Lower Lias.

Fig. 109.—CLIFF SECTION ON THE EAST SIDE OF RAASAY (by Professor Judd). Distance about 5 miles.

w. Tertiary Lava-flow.
l. Estuarine Shales
k. Sandstones
h. Inferior Oolite } Oolitic.
g. Upper Lias
f. Scalpa Beds
e. Pabba Shales
d, *c*. Lower Lias } Liassic series.
b. Trias.
a. Torridon Sandstone.
F.F. Faults.

Upper Lias.—In Rutland and the south of Lincolnshire this division is thicker than usual, having a thickness of 176 feet near Oakham, but thins northward, being less than 100 feet at Lincoln, where, however, it is well exposed and very fossiliferous. Near Lincoln it has been subdivided by Mr. W. H. Dalton as follows :—

		Feet.
Zone of *Am. communis*	Shales with calcareous nodules	38
	Shales with comminuted shells, *Am. communis*, *Nucula Hammeri*, and *Trigonia pullus*	8
Zone of *Am. serpentinus*	Shales with septaria and shelly beds containing *Am. serpentinus*, *Am. heterophyllus*, etc.	45
Zone of *Am. annulatus*	Shales with several layers of argillaceous limestone (fish and insect limestones)	8

5. *Yorkshire*

In the south of Yorkshire, from Brough to Kirby Underdale and Howsham, the Lias is similar in all respects to that of North Lincoln, but as soon as the valley of the Derwent is crossed a change begins to be manifest, both the Middle and Upper Lias swelling out till they again attain a development equal to that of South Lincolnshire. From Howsham the outcrop curves round by Thirsk and Northallerton to the coast between Redcar and Whitby, which exhibits an excellent section of the whole formation except the zone of *Am. planorbis*, which, however, is visible near Market Weighton.

The following is a *résumé* of the coast section : [2]—

Upper, 222 feet	Cement beds and alum shale with *Am. communis*, *Am. bifrons*, and *Nuculana ovum*, about 100 feet.
	Shales with jet beds, *Am. serpentinus*, 92 feet.
	Gray shales with *Am. annulatus*, 30 feet.
Middle, 140 feet	Ironstone (Cleveland main seam) and shales below, zone of *Am. spinatus*, 30-50 feet.
	Ironstone (lower seam) or Pecten bed, with beds of marly sandstone below ; contains *Am. margaritatus* and *Pecten lævis*, about 100 feet.
Lower, 714 feet	Clays with *Am. capricornus*, 130 feet.
	Shaly micaceous clays with *Am. Jamesoni*, 225 feet.
	Clays with *Am. obtusus*, *Am. oxynotus*, and *raricostatus*, 100 feet.
	Shales and limestones with *Am. Turneri* and *Am. semicostatus*, 66 feet.
	Shales and thin limestones, zone of *Am. Bucklandi*, 113 feet.
	Shales and thin limestones, *Am. angulatus*, 30 feet.
	Zone of *Am. planorbis* below, but not accessible (?50 feet).

6. *Ireland*

Beds of Lower Liassic age occur only in the extreme north-east of Ireland ; they crop out at several places in Antrim between the Trias and the Cretaceous series, but are frequently overlapped by the latter, and are then concealed from view. The best sections are at Colin Glen near Belfast, White Head, Island Magee, Larne, and Glenarm, but nowhere is the top of the lower Lias exposed. The following zones are found in descending order :—

4. Clays with *Belemnites acutus*, possibly representing the zone of *Am. Turneri* and *Am. semicostatus.*
3. Blue argillaceous limestones, zone of *Am. Bucklandi.*
2. Blue marly clays with dark limestones, zone of *Am. angulatus.*
1. Black shales with *Am. planorbis.*

At Portrush the Lias shales are indurated and converted into hornstone by contact with igneous rock.

7. *West of Scotland*

The Mesozoic rocks of the Inner Hebrides, like those of Ireland, owe their preservation to the enormous flows of lava which were poured out upon them in Tertiary times, and they now appear only in cliff sections or in valleys where the superincumbent lavas have been removed by subsequent erosion.

The existence of Liassic deposits at certain places on the west coast, and in the islands of Mull, Skye, and Raasay, has been known for a long time, but the most complete account of them is to be found in Professor Judd's masterly paper on the "Secondary Rocks of Scotland."[3] Nearly every zone of the Lias is represented, and the total thickness of the formation is not less than 1200 feet.

Lower Lias.—The very base of this is never clearly seen, so that it is uncertain whether the Rhætics occur below, but Professor Judd believes them to be absent. The lowest beds of the Lias greatly resemble those of the same age in South Wales ; they consist of very hard bluish gray limestones, alternating with calcareous grits and conglomeratic sandstones. The commonest fossil is *Ostrea irregularis* (a variety of *O. liassica*), but corals *Thecosmilia Martini* and *Isastrea Murchisoni* also occur, together with *Cardinia concinna* and spines of *Acrosalenia.* Ammonites are not found, but the beds may be regarded as equivalent to the zones of *Am. planorbis* and *Am. angulatus ;* their thickness is about 200 feet, and they are well seen at Applecross and on the opposite coast of Raasay (see Fig. 109).

The succeeding zone of *Am. Bucklandi* is well developed, and consists of shelly limestones and shales crowded with fossils of the same species which are common in England ; its thickness is 250 feet. Above are dark micaceous shales containing *Am. semicostatus*, *Am. Brooki*, and *Belemnites acutus*, 150 feet. The separate existence of the *Am. oxynotus* zone is not determined, the fossils of this zone only occurring at Tobermory in Mull, where they are mingled with others that belong to higher horizons.

The higher part of the Lower Lias consists of sandy and micaceous shales, called the Pabba Shales by Professor Judd. At the base of these there are some beds in which *Am. armatus* occurs, but the greater portion of the group represents the zones of *Am. Jamesoni* and *Am. capricornus;* these shales contain *Am. Jamesoni*, *Am. brevispina*, *Am. Davœi*, *Modiola scalprum*, and *Gryphæa cymbium*, and are about 250 feet thick.

Middle Lias.—This division consists of gray calcareous sandstones with some beds of calcareous shale. They were termed the Scalpa Beds by Professor Judd, and are well exposed in Scalpa and Raasay, where their thickness is 200 feet. They contain *Bel. paxillosus*, *Am. margaritatus*, *Am. spinatus*, *Pecten æquivalvis*, *Rhynchonella tetrahedra*, and other marlstone fossils. In Mull the Scalpa Beds are represented by soft greenish sandstones with few fossils.

Upper Lias.—As elsewhere this division consists of shales with much pyrites and jet ; the lower portion yields *Am. serpentinus* and *Am. radians*, and the upper beds *Am. communis*, with *Belemnites Voltzi* and *Posidonomya Bronni.* Sections are generally obscured by slips and grass, but the thickness averages from 75 to 80 feet.

8. *North-east of Scotland*

In this region beds of Liassic age have only been found at one locality, namely, in the reefs below Dunrobin Castle on the coast of Sutherland, where they rest on the beds described on p. 322.

Lower Lias.—The lowest beds are clearly of estuarine origin, consisting of sandstones and shales with thin layers of clay and coal, the whole attaining a thickness of between 400 and 500 feet ; no fossils have been found except in the uppermost beds, where a few dwarfed *Gryphæa* and *Cardinia* prove the occasional presence of salt water. As these beds are overlain by clays with *Am. oxynotus*, they must be the estuarine equivalents of the zones of *Am. planorbis* and *Am. Bucklandi.*

The marine beds above exhibit the following succession :—

	Feet.
3. Dark blue micaceous clays with septaria, *Belemnites acutus*, *Am. brevispina*, *Am. Jamesoni*, *Hippopodium ponderosum*, and *Gryphæa cymbium*	80
2. Micaceous sandstones and clays with *Gryphæa obliquata*, *Pecten æquivalvis*, and *Belemnites acutus*	34
1. Blue clays and impure limestones with *Am. oxynotus*, *Am. caprotinus*, *Bel. acutus*, *Cardinia hybrida*, *Lima pectinoides*, and *Gryphæa obliquata*	60

Of these groups the lowest is clearly the zone of *Am. oxynotus*, while Nos. 2 and 3 appear to be the equivalents of the zones of *Am. armatus*, *Jamesoni*, and *capricornus*.

Middle Lias.—No higher beds are seen, but their former existence is proved by the occurrence of boulders of calcareous sandstone, like those of the western coast, in the boulder clays of Moray and Elgin. These boulders enclose such fossils as *Belemnites paxillosus*, *Am. actæon*, *Modiola scalprum*, *Avicula inæquivalvis*, and *Panopæa elongata*, and others which occur in the Scalpa sandstones of the west coast. It is quite possible, indeed, that such rocks (of Marlstone age) may still exist *in situ* beneath the vast masses of glacial clay which mantle the surface of Elginshire.

No proof that Upper Lias was ever deposited on this coast has yet been discovered, and no fossils of that division occur in the boulder clays.

B. Middle Jurassic Series

Subdivisions.—This part of the Jurassic system consists of a variable series of oolitic and shelly limestones and marly clays, none of the strata continuing long of the same thickness, and many beds thinning out altogether within comparatively short distances. The most persistent stratum is that known as the Cornbrash, which lies at the summit of the series. The beds which appear in different districts have for the most part received local names, and the correlation of these subdivisions is not by any means an easy matter, for some of them are of estuarine origin, and in some districts there is evidence of current erosion with a corresponding local absence of certain portions of the series. It is only in the southern counties that a complete succession of marine deposits is found, and this series is divisible into the following groups and zones :—

Bathonian	Cornbrash . .	Zone of Am. macrocephalus.
	Forest marble . .	Zone of Waldheimia digona.
	Great oolite . .	Zone of Nerinæa Voltzi.
	Fuller's earth . .	Zone of Am. subcontractus.

Bajocian	Upper limestones	Zone of Am. Parkinsoni. Zone of Am. humphriesianus.
	Lower limestones	Zone of Am. Murchisonæ.
	Midford Sands	Zone of Am. opalinus. Zone of Am. jurensis.

Life of the Period

Marine Fauna.—The fauna of the Middle Jurassic rocks is closely related generically to that of the Lias, but only about 50 species actually pass from one formation to the other, although each fauna numbers about 2000 species. The fauna of the Oolitic limestones differs from that of the Lias principally in the relative abundance of corals, echinoderms, and gastropods. This, however, is sufficiently explained by the fact that these limestones were evidently formed in the neighbourhood of coral reefs, such reefs at the present day always abounding in sea-urchins and univalve shells. Brachiopoda, too, are individually very abundant, though the number of species is not greater than in the Lias, and the genera are the same, except that *Leptæna* and *Spiriferina* are absent. The following are the more important genera which now appear, and those to which an asterisk is prefixed did not survive the Jurassic period:—

Porifera. Corynella, Craticularia, Elasmostoma, Holcospongia, Lymnorella, Peronidella, Verrucocælia.
Anthozoa. Adelastrea, *Anabacia, Cryptocœnia, Cyathophora, Stylina.
Echinoderma. Apiocrinus, *Clypeus, Collyrites, Nucleolites, Hemicidaris, Holectypus, *Hyboclypus, Pedina, Pygaster, Pygurus, Stomechinus.
Brachiopoda. Terebratella, Terebratulina.
Lamellibranchia. Corbis, Corbicella, Cyprina, Cyrena, Isocardia, *Pachyrisma, Pteroperna, Sowerbya, Spondylus, *Trichites.
Gastropoda. Brachytrema, Bulla, *Cirrus, Dephinula, Fissurella, Nerinæa, Pileolus, *Purpuroidea, Rissoina.
Cephalopoda. The Ammonite genera Cosmoceras, *Haploceras, Lioceras, Ludwigia, *Macrocephalites, Oppelia, *Parkinsonia, Perisphinctes, Sonninia, and Sphæroceras.
Pisces. Aspidorhynchus, Microdon, Strophodus, Ganodus, Ischyodus.
Reptilia. Streptospondylus, Teleosaurus.

The following are lists of the fossils which may be regarded as specially characteristic of the groups indicated:—

Fossils of the Midford Sand and Cephalopoda Bed

Brachiopoda. Rhynchonella cynocephala.
Lamellibranchia. Trigonia striata, Modiola sowerbyana, Gervillia Hartmanni, Cucullæa ferruginea.
Gastropoda. Amberleya capitanea, Trochus duplicatus.

Cephalopoda. Am. (Lytoceras) jurensis, Am. (Ludwigia) opalinus, Am (Grammoceras) striatulus, Am. (Hammatoceras) insignis, Am. (Lytoceras) torulosus, Belemnites irregularis, B. compressus.

Fossils of the Bajocian (Inferior Oolite)

Actinozoa. Anabacia hemispherica, Thecosmilia gregaria.
Echinoderma. Collyrites ringens, Stomechinus germinans, Pygaster semisulcatus, Clypeus Ploti.

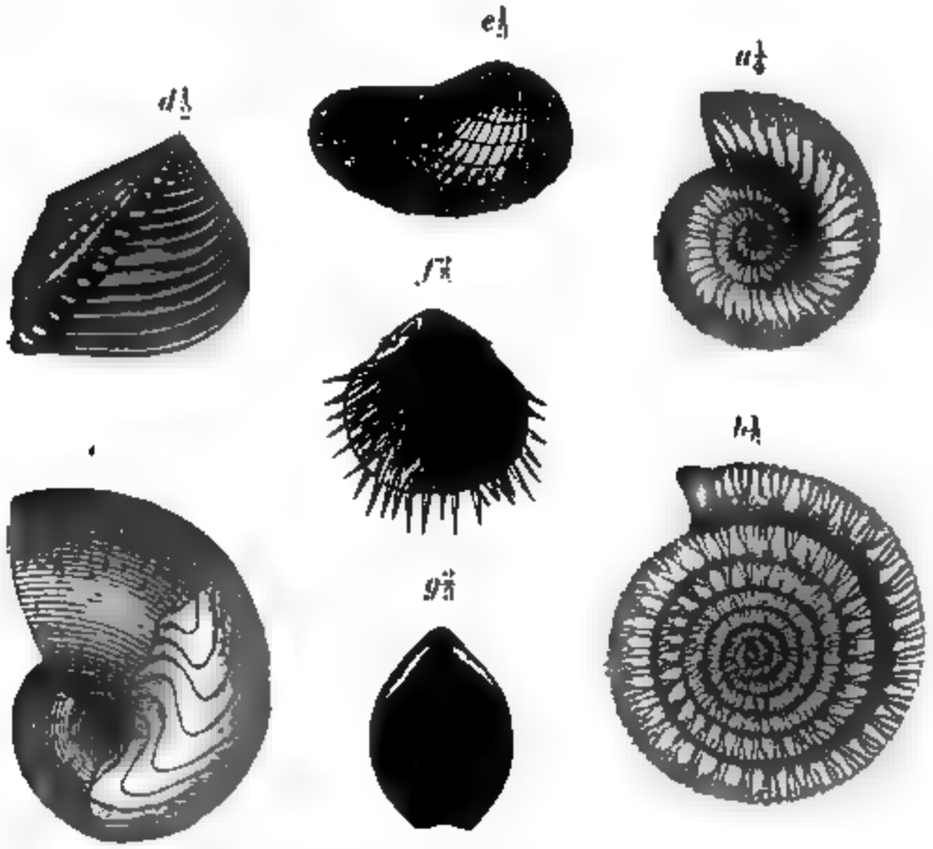

Fig. 110.—GROUP OF INFERIOR OOLITE FOSSILS.

a. Ammonites Parkinsoni.
b. Ammonites humphriesianus.
c. Nautilus sinuatus.
d. Trigonia costata.
e. Pholadomya fidicula.
f. Rhynchonella spinosa.
g. Terebratula perovalis.

Brachiopoda. Rhynchonella spinosa, Terebratula fimbria, T. Phillipsii, T. sphæroidalis, Waldheimia carinata.
Lamellibranchia. Astarte elegans, A. excavata, Ceromya bajociana, Gresslya abducta, Gryphæa sublobata, Lima pectiniformis, Pholadomya fidicula, Trigonia costata denticulata, T. hemispherica.
Gastropoda. Cirrus nodosus, Nerinæa cingenda, Pleurotomaria ornata, Pseudomelania procera, Bourguetia striata.
Cephalopoda. (For Ammonites see *ante*, p. 350), Nautilus truncatus, N. sinuatus.

Fossils of the Great Oolite and Forest Marble

Actinozoa. Anabacia complanata, Isastrea explanatula, Apiocrinus Parkinsoni.

Echinoderma. Acrosalenia hemicidaroides (ranges to Cornbrash), Hemicidaris minor.

Brachiopoda. Rhynchonella concinna, R. obsoleta, Terebratula maxillata, T. coarctata. Waldheimia digona.

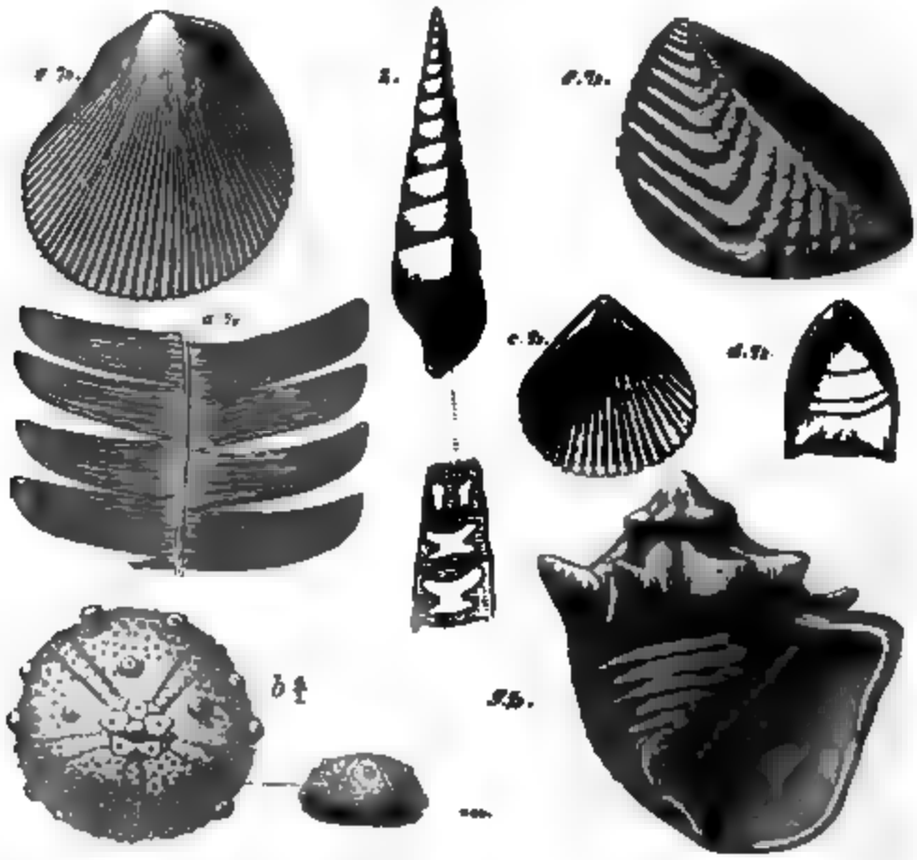

Fig. 111.—GROUP OF FOSSILS FROM THE GREAT OOLITE, INCLUDING STONESFIELD SLATE AND FOREST MARBLE.

a. Pterophyllum comptum.
b. Hemicidaris minor.
c. Rhynchonella concinna.
d. Waldheimia digona.
e. Lima cardiiformis.
f. Trigonia Goldfussi.
g. Purpuroidea Morrisi.
h. Nerinæa Voltzi.

Lamellibranchia. Avicula costata, Trapezium rostratum, Lima cardiiformis, Macrodon hirsonensis, Ostrea acuminata, O. Sowerbyi, Pachyrisma grande, Trigonia Goldfussi, T. Moretoni.

Gastropoda. Alaria armata, Amberleya nodosa, Cylindrites acutus, Purpuroidea Morrisi, Nerinæa Voltzi, Patella rugosa, Nerita costulata.

Cephalopoda. Nautilus Baberi, Ammonites (Perisphinctes) arbustigerus.

Fish. Strophodus magnus, Pholidophorus minor.

Reptilia. Steneosaurus brevidens, Cimoliosaurus erraticus.

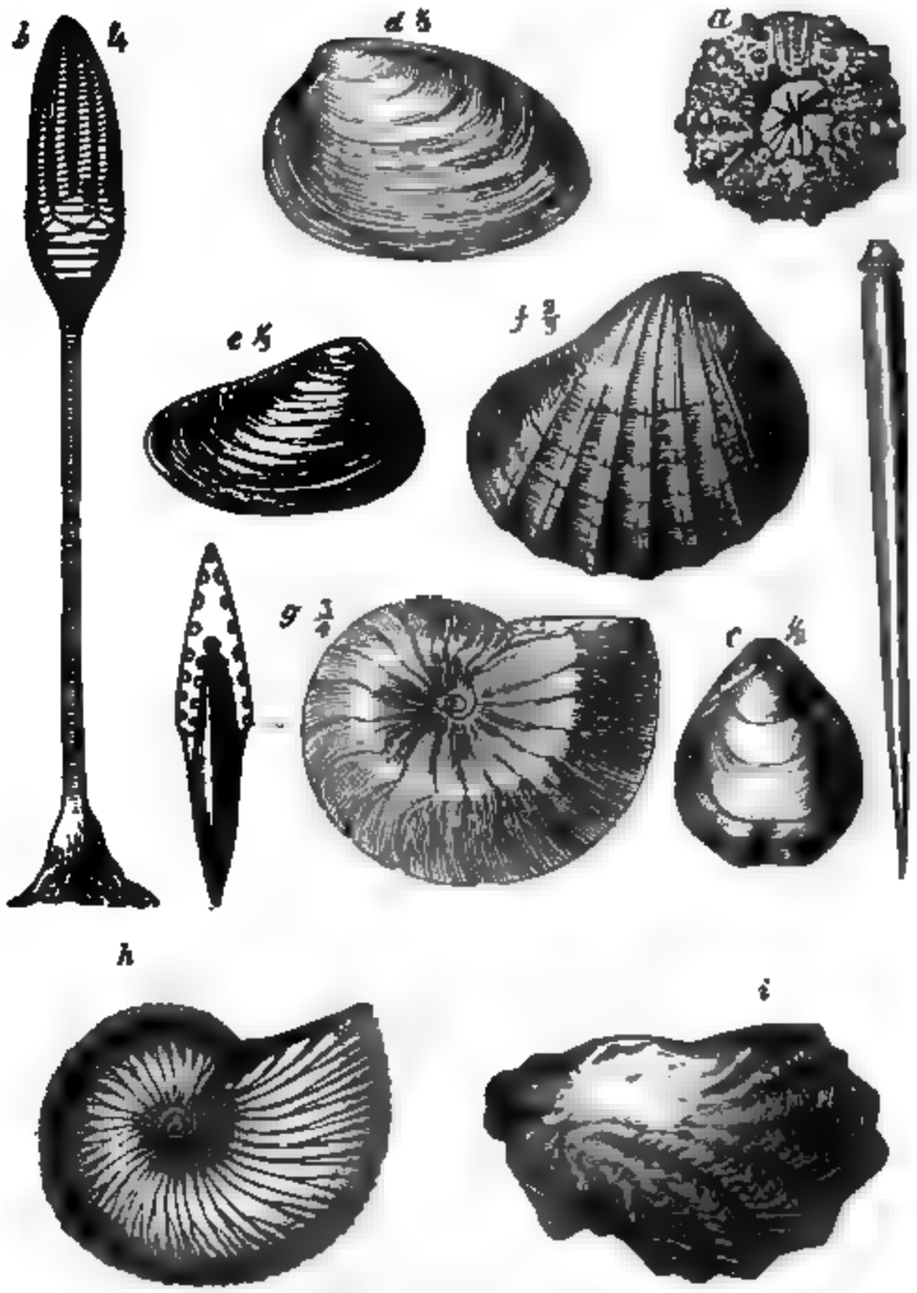

Fig. 112. -GROUP OF CORNBRASH FOSSILS (WITH APIOCRINUS FROM THE BRADFORD CLAY)

a. Acrosalenia hemicidaroides.
b. Apiocrinus Parkinsoni.
c. Terebratula intermedia.
d. Grealya peregrina.
e. Pleuromya decurtata.
f. Phaladomya lyrata.
g. Ammonites discus.
h. Ammonites macrocephalus.
i. Ostrea flabelloides.

Fossils of the Cornbrash

Actinozoa.—Anabacia complanata.
Echinoderma.—Holectypus depressus, Nucleolites clunicularis.

Brachiopoda.—Terebratula intermedia, T. Bentleyi, Waldheimia obovata.

Lamellibranchia.—Pseudomonotis echinata, Pecten vagans, Lima duplicata, Pleuromya decurtata, Gresslya peregrina, Pholadomya lyrata, Ostrea flabelloides.

Gastropoda.—Pseudomelania vittata.

Cephalopoda.—Ammonites (Oxynoticeras) discus, Am. (Macrocephalites) macrocephalus.

Fig. 113.—JAWS OF (1) PHASCOLOTHERIUM BUCKLANDI AND (2) AMPHITHERIUM BRODERIPI FROM STONESFIELD. Natural size with enlarged views of teeth above each.

Terrestrial and Freshwater Fauna.—The estuarine beds which occur occasionally in these rocks furnish us with some interesting remains of the plants and land animals. The borders of

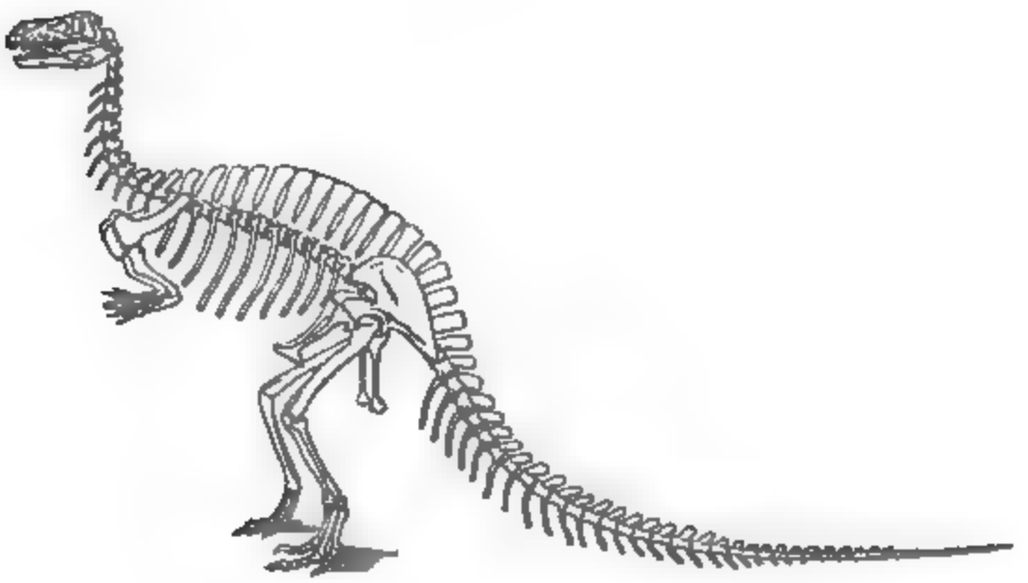

Fig. 114.—RESTORATION OF THE SKELETON OF MEGALOSAURUS BUCKLANDI ($\frac{1}{20}$). Actual length supposed to be about 30 feet.

the rivers and estuaries must have been clothed with a dense vegetation, ferns of the genera *Laccopteris*, *Comopteris*, *Cladophlebis*, *Sphenopteris*, *Tæniopteris;* cycads of many genera, *Williamsonia*, *Ctenis*, *Nilssonia*, *Anomozamites*, *Otozamites*, etc.; coniferous trees, such as *Araucarites*, *Brachyphyllum*, *Baiera*, and *Ginkgo*. Among this vegetation insects abounded, such as beetles, flies, and dragon flies.

In the water lived molluscs of the genera *Cyrena*, *Anodonta*, crocodiles of the Gavial type, and turtles (*Protochelys*).

On land there were small marsupials, *Amphitherium*, *Amphitylus*, *Amphilestes*, and *Phascolotherium* (Fig. 113), and the Prototherе *Stereognathus*. The huge Dinosauria, *Megalosaurus* and *Ceteosaurus*, were also terrestrial creatures (see p. 332).

Stratigraphy

Geographical Range.—Like the Lias, the Middle Jurassic series ranges completely across England from Dorset to Yorkshire. It occupies the Dorset coast between Bridport and Weymouth, and runs inland by Yeovil, Sherborne, and Bruton to the Mendips. In Gloucestershire it gives rise to the well-known scenery of the Cotteswolds, and spreads over a considerable width of country. Thence it passes through the counties of Oxford, Northampton, Rutland, and Lincoln, forming the long escarpment known as the "cliff" in Lincolnshire, which runs due north from Grantham by Ancaster, Navenby, Lincoln, and Kirton to the Humber.

In South Yorkshire it makes but little show, the beds being thin, but north-west of Malton they thicken, and, sweeping round to the north of Helmsley, form the high ground of the Yorkshire

Dorset and South Somerset.	N. Somerset and Gloucestershire.	Oxfordshire.	Northampton, Rutland, and Lincoln.	Yorkshire.
Cornbrash	Cornbrash	Cornbrash	Cornbrash	Cornbrash
Forest Marble	Forest Marble	Forest Marble	Great Oolite clay	Upper estuarine beds
Great Oolite	Great Oolite	Great Oolite	Great Oolite	
Fuller's earth	Stonesfield slate	Stonesfield slate	Estuarine beds	
	Fuller's earth	Absent	Absent	Absent
Inferior Oolite limestone	Ragstones	Ragstones	Absent	Scarborough Limestone
	Freestones and pea-grit	Freestones	Lincolnshire Limestone	Middle estuarine beds Millepore bed
Midford Sand	Cotteswold sands	Northampton beds	Northampton beds	Lower estuarine beds Dogger and sands

Wolds, which range from west to east, and terminate in the cliffs between Whitby and Scarborough.

Rocks belonging to this series occur in Skye and several other islands off the west coast of Scotland; they also form a narrow strip of ground on the east coast of Sutherland.

The stratigraphical variations which this series exhibits along its outcrop in England will be best explained by brief accounts of the succession in five separate districts. The correlation of the deposits found in these districts is shown in the accompanying table. For fuller details the reader is referred to Mr. H. B. Woodward's memoir.[5]

1. *Dorset and South Somerset*

Inferior Oolite Group.—In this southern district the limestones of the inferior oolite are of small thickness, while the Midford Sands, which represent the zones of *Am. jurensis* and *Am. opalinus*, are from 150 to 180 feet thick. On the coast near Bridport there is little more than 10 feet of limestone, but inland these beds become a little thicker, and the following is the succession, A on the coast and B near Beaminster :—

	A. Feet.	B. Feet.
4. Gray oolitic limestones with *Am. Parkinsoni* and *Terebratula spheroidalis*	7	6
3. Gray and brown limestones with *Astarte excavata* .	2½	8
2. Brown earthy limestones with *Am. concavus*, *Am. Murchisonæ*, and other fossils	3	18
1. Yellow micaceous sands with nodular layers of calcareous sandstone (Midford Sand)	150	150

Fossils are scarce in the lower part of the Midford Sand, but near the top *Am. opalinus*, *Am. torulosus*, *Rhynch. cynocephala*, and other fossils have been found. The zone of *Am. humphriesianus* is not well developed, for though that species occurs in the middle limestones (No. 3) it is not common, and *Am. Parkinsoni* occurs with it. The lower part of No. 4 is called the "Terebratula bed," from the abundance of *Ter. spheroidalis*, *Ter. Phillipsi*, and *Waldheimia carinata*.

In Somerset, north of Crewkerne, beds of freestone make their appearance in the Midford Sands, and are quarried at Ham Hill, where the beds exposed are as follows :—

		Feet.
Midford Sands	Yellow sand and soft sandstones	40
	Yellowish brown limestone, consisting of comminuted shell-fragments, current bedded, and cutting as a freestone	50
	Yellow sands with layers of calcareous stone . .	80

The shells in the freestone which is known as "Ham Hill stone" are all so broken that *Rhynch. cynocephala* alone has been recognised.

Near Yeovil the Midford Sands are about 180 feet thick, and the lower beds contain *Am. jurensis* and *Am. Moorei*, while *Am. opalinus* has been found in the upper 30 feet.

The best sections of the overlying limestones are found in quarries between Yeovil and Sherborne, where the following zones have been recognised by Mr. S. S. Buckman :[6]—

	Feet.
5. Limestone with Am. Parkinsoni .	15 to 45
4. ,, ,, Am. humphriesianus	1 to 6
3. ,, ,, Am. concavus .	3 to 4
2. ,, ,, Am. Murchisonæ .	1 to 6
1. Sandy limestone with Am. Moorei .	1 to 2

The lowest bed forms a passage into the underlying sand, and probably belongs to the zone of *Am. opalinus*. The total thickness varies from 30 to 60 feet.

Great Oolite Group.—The lowest member of this group is the Fuller's Earth, which attains a great thickness in Dorset (400 feet). It was formerly regarded as more closely connected with the Inferior Oolite than with the Great Oolite, but Mr. H. B. Woodward has shown that its Ammonites clearly unite it to the Great Oolite, and that the larger proportion of its fossils range upward. He also remarks that *Am. subcontractus* is its characteristic Ammonite ; of other fossils *Ostrea acuminata*, *Rhynchonella varians*, and *Waldheimia ornithocephala* are the commonest.

The Fuller's Earth is a marly clay, generally of a greenish or yellowish gray, but sometimes blue, and some of its beds consist of the fine soft greasy clay which is used for fulling purposes. It also includes a band of earthy limestone which is known as the Fuller's Earth Rock. This rock is thickest in Somerset, where it is often from 25 to 30 feet thick. The formation, however, is not more than 130 feet thick in this country.

No limestone comparable to the Great Oolite of more northern districts is found in the area south of the Mendips, and the Fuller's Earth is directly succeeded by the Forest Marble. The absence of the Great Oolite limestone is probably due to the action of currents which either prevented its deposition, or eroded and removed so much of it as may have been formed.

The Forest Marble consists of shelly and flaggy limestones, which show much oblique current bedding, and alternate with bands and layers of shaly clay or marl. It was formerly supposed to be over 400 feet thick, but Mr. Woodward has found this to be a mistake ; on the coast near Bridport it is only about 80 feet thick,

and its greatest thickness is not in Dorset, but in Somerset, near Sherborne, where it is about 130 feet. The limestones have been quarried at many places for building and paving stones.

The Cornbrash in Dorset and Somerset is from 15 to 25 feet thick, and consists of rubbly ferruginous limestone of a bluish gray colour in its deeper parts, but weathering into a brown rock by oxidation of the iron, and forming a fertile soil. It generally yields a number of fossils, especially of echinoderms, brachiopods and lamellibranchs (see list on p. 353).

2. *Gloucestershire*

The area to which the following account applies is that of the country round Bath and along the Cotteswold Hills from Bradford-on-Avon to the district between Cirencester and Cheltenham.

Inferior Oolite Group.—Along this line of country the lower part of the series is divisible as follows:—

		Zones.	Thickness.
Inferior Oolite	Ragstones	*Am. Parkinsoni*	20 to 40
	Freestones	*Am. Murchisonæ*	25 ,, 160
	Pea-grit and brown limestones	*Am. Murchisonæ*	10 ,, 45
Midford Sand	Cephalopoda bed	*Am. opalinus*	2 ,, 15
	Cotteswold sands	*Am. jurensis*	120 ,, 40
			177 to 300

The "Cephalopoda bed" consists of brown ironshot marly limestone in two or more layers; it has yielded no fewer than sixteen species of Ammonites, and is sometimes divisible into two or three sub-zones. *Rhynchonella cynocephala* is also common in it.

The "Pea-grit" is a bed of coarse pisolitic limestone from 4 to 20 feet thick, which is traceable along the Cotteswolds for 20 miles, and generally has some beds of brown ferruginous oolitic limestone below it (see Fig. 115).

The Freestones are soft, pale-coloured oolites in thick beds, and are locally separated into lower and upper freestones by a band of yellowish oolitic marl full of *Terebratula fimbria*. Ammonites are rare in these beds, and the fauna consists mainly of lamellibranchs, brachiopods, and corals, but *Am. humphriesianus* has been found in the upper freestones.

The Ragstones are a set of hard, gray, shelly, oolitic, and marly limestones which are generally full of fossils, and the prevalence

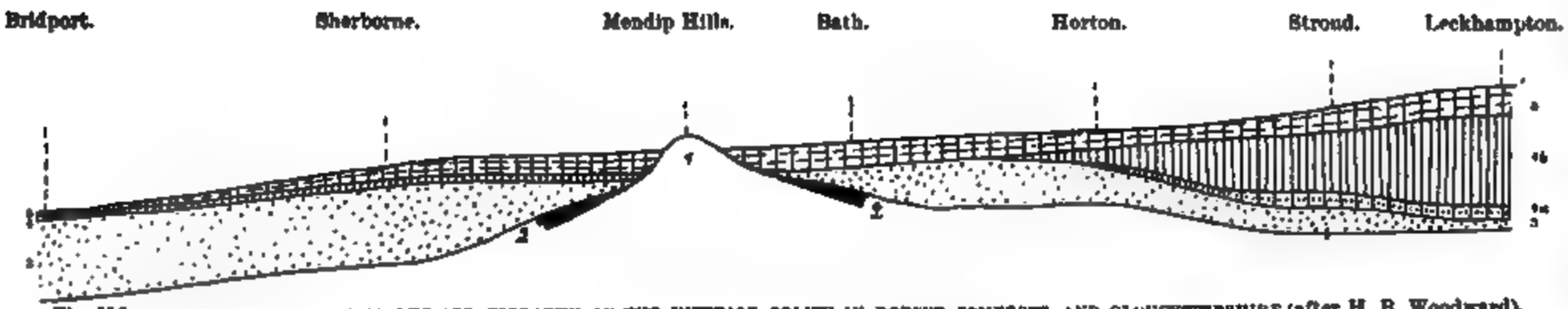

Fig. 115.—DIAGRAMMATIC VIEW OF THE STRATIGRAPHY OF THE INFERIOR OOLITE IN DORSET, SOMERSET, AND GLOUCESTERSHIRE (after H. B. Woodward). Distance about 90 miles. Vertical scale about 200 feet to an inch.

5. Ragstones
4b. Freestones } Inferior Oolite.
4a. Pea-grit
3. Midford and Cotteswold Sands.
2. Lias, overlapped on the Mendip ridge.
1. Palæozoic rocks.

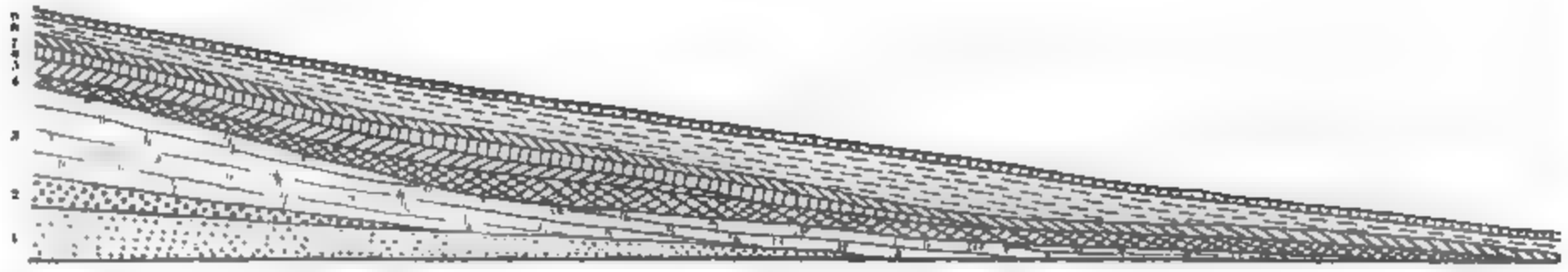

Fig. 116.—DIAGRAM SECTION FROM THE COTTESWOLD HILLS TO FAWLER IN OXFORDSHIRE (after H. B. Woodward). Distance about 25 miles. Vertical scale 240 feet to an inch. The top of the Lias is taken as a horizontal plane.

9. White Oolite, etc.
8. Clypeus grit.
7. Upper Trigonia grit.
6. Gryphite and Lower Trigonia grits.
5. Upper freestone.
4. Oolitic marl.
3. Lower freestone.
2. Pea-grit group.
1. Cotteswold sand.

of certain species in some of the beds has led to their being distinguished locally by different names, such as Trigonia beds, Clypeus grit, and Gryphite grit.

Near Cheltenham the limestones of the Inferior Oolite are about 250 feet thick.

Great Oolite Group.—The Fuller's Earth is traceable through the district, but thins northward. Near Bath it is from 70 to 80 feet thick, but not more than 40 or 50 near Chedworth, where it passes up into the beds which are known as the Stonesfield slate; these are shales and laminated micaceous sandstones which are thin in Gloucestershire, but become of more importance in Oxfordshire.

The Great Oolite limestone first sets in near Bradford-on-Avon, and rapidly thickens northward till, near Bath and Minchinhampton, it is from 80 to 100 feet, and includes the well-known freestone which goes by the name of "Bath Oolite." Here it consists of the following beds:—

		Feet.
Upper division—Shelly and oolitic limestones		20 to 50
Lower division	Oolitic freestone	10 to 30
	Shelly and marly limestones	10 to 40

The Forest Marble succeeds, and near Bradford and Bath its basement bed is a band of bluish gray clay, which is known as the Bradford Clay, but is never more than 10 feet thick. It contains many fossils in a fine state of preservation, and has long been known for the abundance of *Apiocrinus Parkinsoni* (the pear encrinite). It also contains *Waldheimia digona*, *Terebratula coarctata*, and other fossils which are characteristic of the overlying Forest Marble beds. The latter are from 60 to 100 feet thick, and consist of alternating limestones and clays.

The Cornbrash forms a persistent band at the top of the series, but is never more than 15 feet thick.

3. *Oxford and Northampton*

Inferior Oolite Group.—In passing from Gloucester into Oxfordshire, and thence into Northampton, the Inferior Oolite undergoes much alteration. In the first place, the lower members of the series thin out and are overlapped by the higher portions, till near Fawler the "Trigonia grit," a bed in the Ragstone group, comes to rest directly and unconformably on the Upper Lias clay. Fig. 116 illustrates this thinning out of the beds between Cheltenham and Fawler, and the succession found at Fawler is as follows:—

		Feet.
Ragstones.	Chipping Norton limestone—oolitic limestone	12 to 15
	Clypeus grit—rubbly and marly oolites	8 to 12
	Trigonia grit: Marly limestones	5 to 6
	Trigonia grit: Hard oolitic limestones with pebble bed at base	4

From the basement bed Mr. E. A. Walford[7] obtained small blocks of limestone covered with *Plicatulæ* and pierced by *Lithodomi*, showing that some of the lower limestones had been deposited in the near neighbourhood, and underwent erosion before the formation of the Trigonia grit. Near Hook Norton the Ragstones are reduced to a thickness of about 22 feet, and the lowest beds contain similar bored stones, but here they rest on a representative of the *opalinus* zone, consisting of sandy limestones about 6 feet thick, in which *Am. opalinus*, *Rhynch. cynocephala*, and other fossils occur; these beds also have a pebbly base resting on Upper Lias clay.

When we reach the valley of the Cherwell we find no limestones at all, the Inferior Oolite being represented only by 10 or 12 feet of brown sandstone and sandy ironstone, overlain by calcareous flagstones ("plank beds"). These sandy beds thicken out rapidly again to the north-east, and in spite of the lithological dissimilarity they are considered as equivalent to the lower part of the Inferior Oolite of Cheltenham, *i.e.* the zones of *Am. opalinus* and *Am. Murchisonæ*. Near Northampton the succession is as follows:—

		Feet.
Lower Estuarine	White or gray sand, containing a plant bed	12
	White sand and ferruginous sandstone with shelly calcareous beds, very variable	up to 30
Ironstone beds	Coarse oolitic limestone	4
	Sandy ironstones, with *Rhynch. cynocephala*, *Rh. variabilis*	35

To these beds the name of Northampton Sand has been applied.

Great Oolite Group.—This group is on the whole more persistent than that of the Inferior Oolite. The main divisions continue through Oxfordshire, and near Chipping Norton the following is the succession:—

	Feet.
Forest Marble	15 to 20
Great Oolite limestone	40 to 50
Stonesfield Slate	15 to 18
Fuller's Earth	6 to 20

The Fuller's Earth is very thin in places, and becomes practically the basal part of the Stonesfield Slate, which consists of flaggy sandstones and sandy clays. These beds have yielded a remarkable assemblage of fossils, including remains of five genera of small

mammals—two Pterodactyles, three Crocodiles, the Dinosaur *Megalosaurus*, and the Turtle *Protochelys*, with a large number of fish and of mollusca. Among the latter are *Ammonites discus*, *Am. gracilis*, *Nerita costulata*, *Trigonia impressa*, *Gervillia acuta*, *Modiola imbricata*, with *Rhynchonella concinna*. Besides these are remains of ferns, cycads, and conifers.

When traced northwards into Northampton the Stonesfield Slate and Fuller's Earth are found to pass into a set of sands and clays which are called the Upper Estuarine series. In the absence of the Inferior Oolite limestone these beds rest on the Estuarine Beds of the Northampton group, but the two estuarine groups are sharply divided from one another, the base of the upper group being a layer of ironstone nodules which rests on an eroded surface of the lower sands.

The Great Oolite consists of hard limestones alternating with marly clays. These beds contain *Gervillia Waltoni*, *Astarte angulata*, *Terebratula maxillata*, *Rhynchonella concinna*, and many other fossils, and near Fairford is a white limestone which has yielded many corals, such as *Isastrea explanatula*, *I. limitata*, and *Thamnastrea Lyelli*.

The Forest Marble derives its name from Wychwood Forest near Burford in Oxfordshire, where it has been largely quarried. It is continued into Buckinghamshire, but near Buckingham the limestones thin out, leaving only the clays to represent this member of the series ; these form a band which is known as the Great Oolite clay, but it is only from 10 to 20 feet thick.

4. *Rutland and Lincoln*

Inferior Oolite Group.—The Northampton Sand continues as the lowest member of this group, and consists, as in Northampton, of ironstone at the base, passing up into yellow sands, which are succeeded by white sands and pale clays (Lower Estuarine Beds). Between these and the Upper Estuarines a thin wedge of limestone appears in the valley of the Welland, and rapidly thickens northwards, becoming the important formation known as the Lincolnshire Limestone, which in South Lincolnshire is not less than 150 feet thick.[8]

At its base in South Lincolnshire are some beds of fissile sandy limestone, which form a passage from the Lower Estuarine Beds ; these contain ferns (*Laccopteris polypodioides*), with *Lucina Wrightii*, *Gervillia acuta*, *Trigonia compta*, *Tr. impressa*, *Astarte elegans*, and *Malaptera Bentleyi*, but no Ammonites. At Collyweston (near Stamford) these beds are 12 feet thick, but they thin northward, and are hardly distinguishable at Ancaster.

The Lincolnshire Limestone frequently contains beds in which corals are very abundant, and which have evidently been accumulated in the neighbourhood of coral reefs. The upper layers, too, invariably exhibit much current bedding, indicating shallow water conditions. Ammonites are rare, but *Am. Murchisonæ*, *Am. Sowerbyi*, and *Am. subradiatus* have been found. Echinoderms are not uncommon. Gastropods (*Natica Nerinæa*, *Patella*, *Pleurotomaria*, *Trochus*, *Trochotoma*) are common. *Rhynchonellæ* and Lamellibranchs of many species are abundant. The fauna has eminently a shallow water and coral reef facies, and in point of time the limestone appears to be the representative of the Pea-grit and lower Freestones of Gloucestershire (zone of *Am. Murchisonæ*). The Ragstone division is absent, and there is evidence of a gap with erosion between the limestone and the overlying Great Oolite in Rutland and Northampton.

The Lincolnshire Limestone affords excellent building stone, which is largely quarried at Ketton, Casterton, Stamford, Corby, Ancaster, Lincoln, and other places. In North Lincolnshire its thickness again diminishes to about 60 feet.

Great Oolite Group.—This group consists of four members, which are persistent through the whole district, though they vary somewhat in thickness; they are—

	Feet.
4. The Cornbrash	about 15
3. The Great Oolite clays	,, 20
2. The Great Oolite limestone	,, 20
1. The Upper Estuarine Beds	,, 30

The Upper Estuarine Beds consist of white, blue, green, and variegated clays, with seams of lignite and occasional courses of sandy stone; the basement bed is a brown ferruginous nodular sandstone, which rests unconformably upon the Lincolnshire limestone in Rutland and Northampton, though in Lincolnshire no such evidence of erosion has been observed. The fossils are sometimes marine, sometimes estuarine forms (*Cyrena*, etc.).

The Great Oolite limestone consists of soft, white, marly limestones, separated by layers of marly clay. The prevalent fossils are *Ostrea Sowerbyi*, *O. subrugulosa*, *Homomya gibbosa*, and *Clypeus Mulleri*.

The Great Oolite clays are of many colours—blue, green, yellow, and purple; the only fossils are *Placunopsis socialis* and the oysters above mentioned.

The Cornbrash is as usual full of fossils; *Holectypus depressus*, *Nucleolites clunicularis*, *Pseudomonotis echinata*, and *Ammonites macrocephalus* are characteristic and common.

5. *Yorkshire*

Inferior Oolite Group.—In South Yorkshire the Middle Jurassic series is quickly overstepped by the Cretaceous rocks, but beds of the Lincolnshire type are seen near South Cave. When they again emerge in North Yorkshire the series has undergone much transformation, and the mass of the Inferior Oolite consists of Estuarine sandstones and shales 300 or 400 feet thick. Marine beds, however, occur at the top and bottom, and also as a thin zone in the midst of the Estuarine series, the succession being as follows, and the thicknesses those in the cliff sections:[9]—

	Feet.
6. Scarborough Limestone	20 to 90
5. Estuarine beds	50 to 100
4. Millepore beds (marine)	20 to 40
3. Lower Estuarine series	200 to 280
2. The "Dogger" sands and sandstone	30 to 36
1. Blue Wyke sands	40 to 70

1. At the top of the Lias are 80 feet of sandy shales (passage beds) which contain *Ammonites striatulus*, and represent the zone of *Am. jurensis*. Above these shales are yellow and gray micaceous sands containing *Ammonites aalensis*, *Lingula Beani*, *Rhynchonella cynocephala*. They are surmounted by a sandy oolitic ironstone, which contains many fossils: *Am. Murchisonæ*, *Terebratula trilineata*, and *Nerinæa cingenda;* these sands and sandstone may be regarded as the equivalent of the Northampton Sands.

2. The Lower Estuarine series is very thick, and includes the "Great Sand-rock," which is largely used as a building-stone in Eskdale. On the coast these beds appear in the cliffs from Robin Hood's Bay to Huntcliff. The shales and oolitic ironstones contain plant remains in some abundance. In the midst of this series is a band of flaggy sandstone and ironstone with marine fossils known as the Eller Beck bed. It yields *Gervillia acuta*, *Astarte minima*, *Pholadomya Heraulti*, etc.

3. The Millepore beds consist of a hard calcareous sandstone with the Bryozoan *Haploœcia straminea*, overlain by shales and sandstones containing *Trigonia reticosta*, *Ceromya bajociana*, *Gervillia lata*, *Pygaster semisulctus*, and other fossils.

4. The Middle Estuarine series consists of shales and sandstones, with thin layers of coal varying from 2 to 18 inches in thickness. The "plant bed" of Gristhorpe Bay has yielded fine specimens of ferns (*Cladophlebis*, *Sphenopteris*, *Tæniopteris*, etc.), the cycads *Nilssonia* and *Otozamites*, and the horsetail *Equisetites columnaris*.

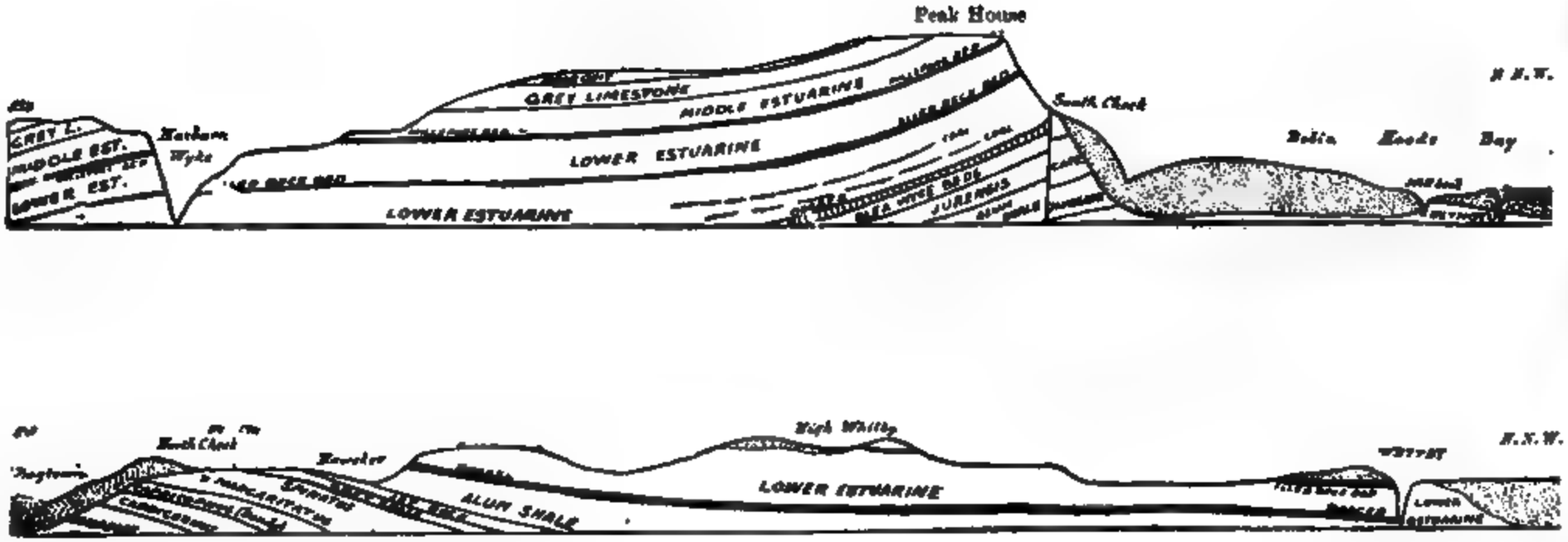

Fig. 117.—SECTION ALONG THE YORKSHIRE COAST FROM HAIBURN WYKE TO WHITBY (by Professor J. F. Blake, *Proc. Geol. Assoc.* vol xii. p. 116). Distance about 13 miles.

The beds exposed belong to the Middle and Upper Lias and the Inferior Oolite. The dotted portions represent Glacial deposits (mainly boulder clay).

5. The beds termed the Scarborough Limestone are gray, shaly limestones, often ferruginous; they contain *Ammonites humphriesianus*, *Gervillia acuta*, *Pseudomonotis braamburiensis*, etc. They form a lenticular mass, very thin at Gristhorpe, but thickening to the north-west.

Groups 3 and 4 certainly represent the Lincolnshire Limestone, and the Scarborough Limestone appears to be the zone of *Am. humphriesianus*.

Great Oolite Group.—The limestone of the Great Oolite has entirely thinned away beneath the Cretaceous overstep, and the whole group is represented on the Yorkshire coast by shales and sandstones of estuarine origin, capped by a thin band of Cornbrash with marine fossils.

In Gristhorpe Bay this Estuarine series is 120 feet thick, consisting of marine sandstones in the lower part, and shales with thin sandstones above. Farther north they are over 200 feet thick. A few ferns are the only fossils.

The Cornbrash is very thin, only 5 or 6 feet, but has the usual characters, being a gray, rubbly ironshot limestone full of the ordinary fossils, among which are *Ammonites Herveyi*, *Pseudomonotis echinata*, *Lima rigidula*, and *Waldheimia lagenalis*.

6. *West of Scotland*

At certain localities in the Inner Hebrides strata occur between the Lias and the Tertiary lavas which are comparable to our English Oolites, more especially to those of the Yorkshire area (see Fig. 109).

Inferior Oolite Group.—"Rocks of this age," says Professor Judd, "must have originally had a very wide distribution, for traces of them are found at various points from the Shiant Isles in the north to Ardnamurchan in the south. The best exposures of their strata, however, are those which occur in the islands of Skye and Raasay."[10] Here the succession is as follows :—

	Feet.
Limestones almost wholly made up of comminuted shells, *Ostrea Sowerbyi*, *Waldheimia lagenalis* = ? zone of *Am. Parkinsoni*	45
Beds of white sandstone with thin shaly bands containing remains of ferns and cycads	60
Beds of sandstone and shale, the former passing into shelly limestones, *Am. humphriesianus*, *Belemnites giganteus*	160
Sandy micaceous shales alternating with calciferous sandstones, *Ammonites Murchisonæ*, *Am. corrugatus*, *Belemnites giganteus*, *Lucina Wrightii*, etc.	120
	385

Great Oolite Group.—The Inferior Oolite of Skye and Raasay is succeeded by a considerable thickness of estuarine strata, which occupy the position of the Great Oolite, and are probably not less than 500 feet thick, although in those islands they are imperfectly exposed. Southwards in the islands of Eigg and Muck this group acquires still greater proportions, and is exposed in clearer sections.

A. The lowest beds are fine conglomerates and shelly limestones full of freshwater shells, but containing also remains of *Plesiosaurus*, turtles, and other reptiles. Above these are black shales and limestones abounding in Cyprids, fish remains, and shells of *Cyrena*, *Cyclas*, and *Viviparus*. The thickness of the whole group is 200 feet.

B. Gray and white sandstones, sometimes passing into calcareous grits, with large concretionary siliceous masses; current-bedding and ripple-marked surfaces are frequent, but excepting plant remains fossils are rare. Thickness probably more than 500 feet.

C. The highest beds are black shales with thin bands of argillaceous limestone and bands of fibrous carbonate of lime; they are sometimes crowded with *Cyrena* and *Cyclas*, and in other places with *Viviparus*, *Melania*, and other Gastropoda. Beds entirely composed of oysters (*O. hebridica*) also occur, resembling those in the Purbeck series (see *postea*). Thickness 150 feet.

7. *East of Scotland*

Beds of Middle Jurassic age occupy a small space on the coast of Sutherland south of Brora, and form two small patches at Burgh Head and Stotfield, on the coast of Elgin. They consist entirely of estuarine strata, which are lithologically comparable to those of the Great Oolite group on the western coast. The descending succession near Brora is as follows:—

	Feet.
"Roof bed," calcareous sandstone (Kellaway). Coal composed of crushed *Equisetites*	3½
Black shales with thin coal-seams in the upper part; plants and crushed shells of *Unio*, *Ostrea*, *Cyrena*, etc., abound; also teeth and scales of fish, *Lepidotus*, *Pholidophorus*, and *Hybodus*	26
Black, brown, and gray clays with layers of argillaceous limestone, *Cyrena* and *Ostrea*	96
White sandstones with some beds of clay; in this a few obscure marine shells occur	110

The base is not seen, and whether any beds comparable to the Inferior Oolite of the west coast exist below is, therefore, unknown.

At Stotfield there are soft, greenish white sandstones containing an assemblage of fossils which might be either of Great or Inferior

Oolite age, though the presence of *Ostera Sowerbyi*, *Tancredia axiniformis*, *Astarte rhomboidalis*, and *Pholadomya oblita* suggest Great Oolite affinities.

C. Upper Jurassic Series

Subdivisions and Geographical Range.—The Upper Jurassic series, where fully developed, as in the south of England, consists of four groups of marine strata, two great argillaceous formations (the Oxford and Kimeridge Clays), each surmounted by a group of limestones (the Corallian and the Portlandian). Above the Portland group are the Purbeck Beds, a set of estuarine and terrestial strata, which are by some united with the Wealden and placed in the Cretaceous system. The Portland and Purbeck Beds are, however, so intimately connected that it would be highly inconvenient to regard the Jurassic system as terminating with the former group, for many of the Portlandian species occur in the intercalated marine beds of the Purbeck group.

On the south coast the cliffs near Weymouth and Portland expose good sections of all these rocks, but the inland outcrop of the Portland and Purbeck Beds is repeatedly concealed by the overstep of the Cretaceous strata. They appear, however, for a space near Tisbury in the vale of Wardour, and again near Devizes. From Calne and Swindon their outcrop is more continuous through Oxford, Berkshire, and Buckinghamshire, but the limestones die out in the last county, and only the clays remain through Bedford, Cambridge, Huntingdon, and Lincoln. In South Yorkshire they are entirely concealed by the Cretaceous overstep, but in North Yorkshire there is a fine development of the Oxfordian, Corallian, and Kimeridgian groups. In Scotland the Oxford Clay exists on the west coast, and the complete series is found on the coast of Sutherland.

With regard to the eastward extension of these rocks beneath the newer systems in the south-east of England we have the testimony of four important borings. The Sub-Wealden boring near Battle traversed all the groups, and a large part of the Oxfordian, terminating at a depth of 1905 feet from the surface. In the Dover boring all the members of the series were found to be greatly reduced in thickness, the combined thickness of the Portlandian, Kimeridgian, Corallian, and Oxfordian being only 452 feet. A boring at Chatham proved the existence of Oxford Clay immediately below the Lower Greensand, a fact which makes it probable that there was considerable erosion of the Upper Jurassic series before the deposition of the Lower Cretaceous

sands in that district. There is a similar gap and unconformity at Richmond, where a boring found the Lower Greensand resting directly on Great Oolite. It is probable that the Oxfordian, Corallian, and Kimeridgian groups originally spread over the area which underlies the Thames valley, but no traces of them have been found in any of the deep borings in Essex, Suffolk, or Norfolk, where Cretaceous rocks everywhere rest directly on a plateau of Palæozoic rocks.

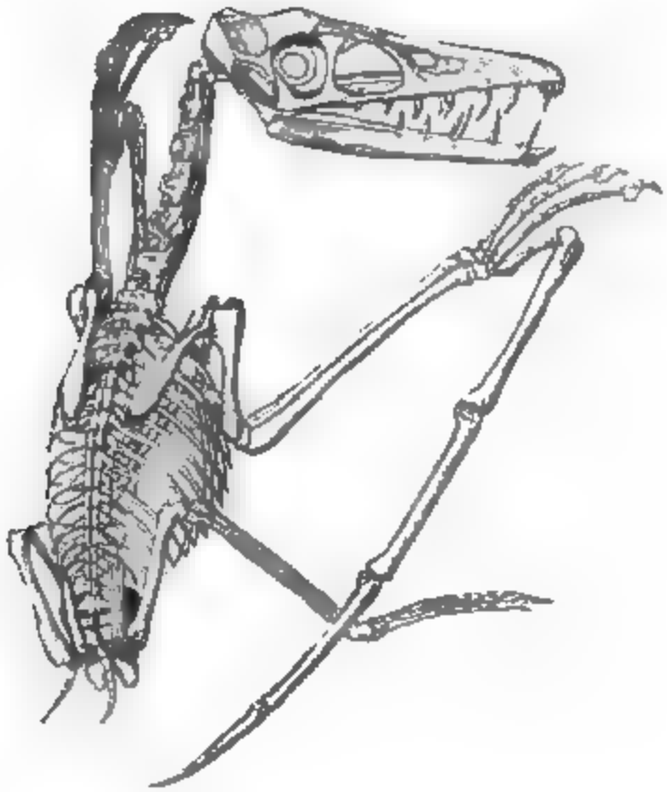

Fig. 118.—SKELETON OF SCAPHOGNATHUS CRASSIROSTRIS (¼) FROM SOLENHOFEN, GERMANY.

Life of the Period

The Upper Jurassic fauna is merely a continuation of that which preceded it, the genera being the same, though the species are for the most part different, only about sixty species passing from the Cornbrash into Oxford Clay.

The most impressive feature of the later fauna is the abundance of reptilian remains. The Jurassic period has been termed the "age of reptiles," and these creatures seemed to have reached the climax of their dominion towards the close of the period. Their numbers and the variety of their modifications are quite extra-

ordinary. Not only did they swarm in the seas and rivers, but they peopled the land with gigantic herbivores, and filled the air with winged forms. They thus adapted themselves for all kinds of food and all conditions of life with an elasticity of organisation which is truly remarkable, and to which no parallel can be found in the subsequent history of the world, unless it is among the Australian marsupials, though no member of that order possesses powers of flight comparable to those of the Pterodactyles.

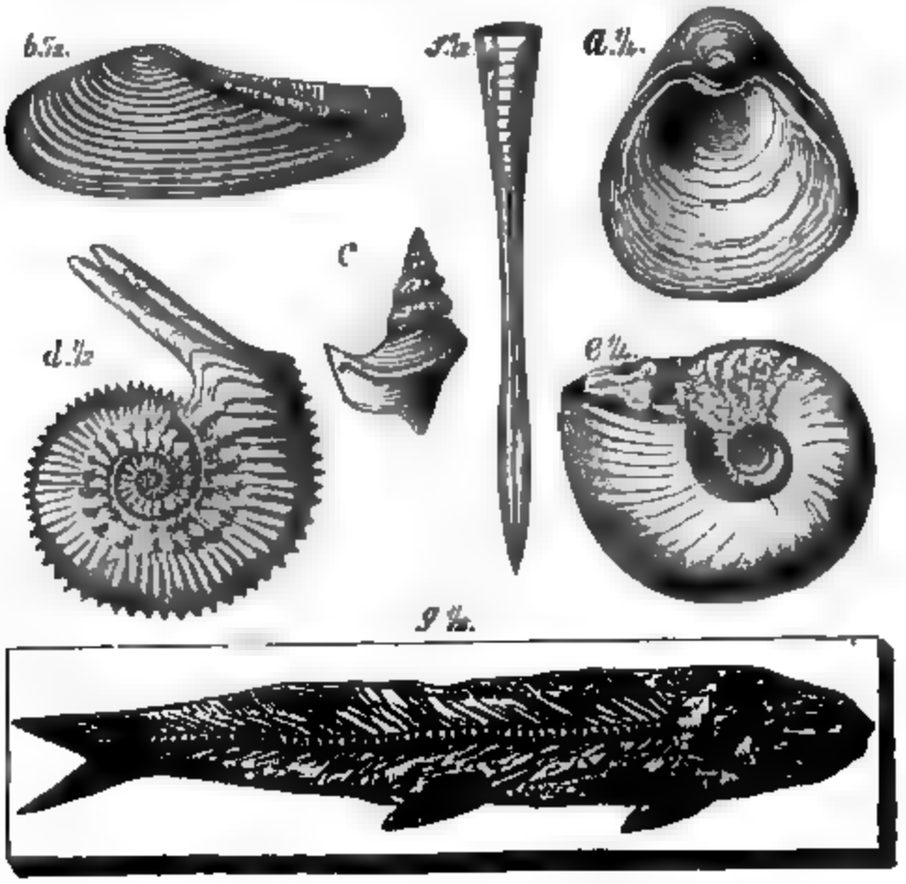

Fig. 119.—GROUP OF OXFORDIAN FOSSILS.

a. Gryphæa dilatata.
b. Anatina undulata.
c. Alaria composita.
d. Ammonites Jason.
e. Ammonites excavatus.
f. Belemnites hastatus.
g. Leptolepis macrophthalmus.

Of Upper Jurassic reptiles, *Cimoliosaurus*, *Peloneustes*, *Pliosaurus*, *Ichthyosaurus*, with the crocodiles *Teleosaurus*, *Steneosaurus*, *Dakosaurus*, and *Goniopholis* were the chief aquatic genera. *Celeosaurus*, *Gigantosaurus*, *Iguanodon*, *Omosaurus*, and *Cryptosaurus* were terrestrial Dinosaurs, and in America other remarkable genera, *Brontosaurus* and *Atlantosaurus*, both of enormous size, have been found. Of Pterosauria species of *Pterodactylus*, *Scaphognathus*, and *Rhamphorhyncus* were prevalent.

Of marine Invertebrates very few new genera make their appearance in these rocks, the following only being worthy of note :—

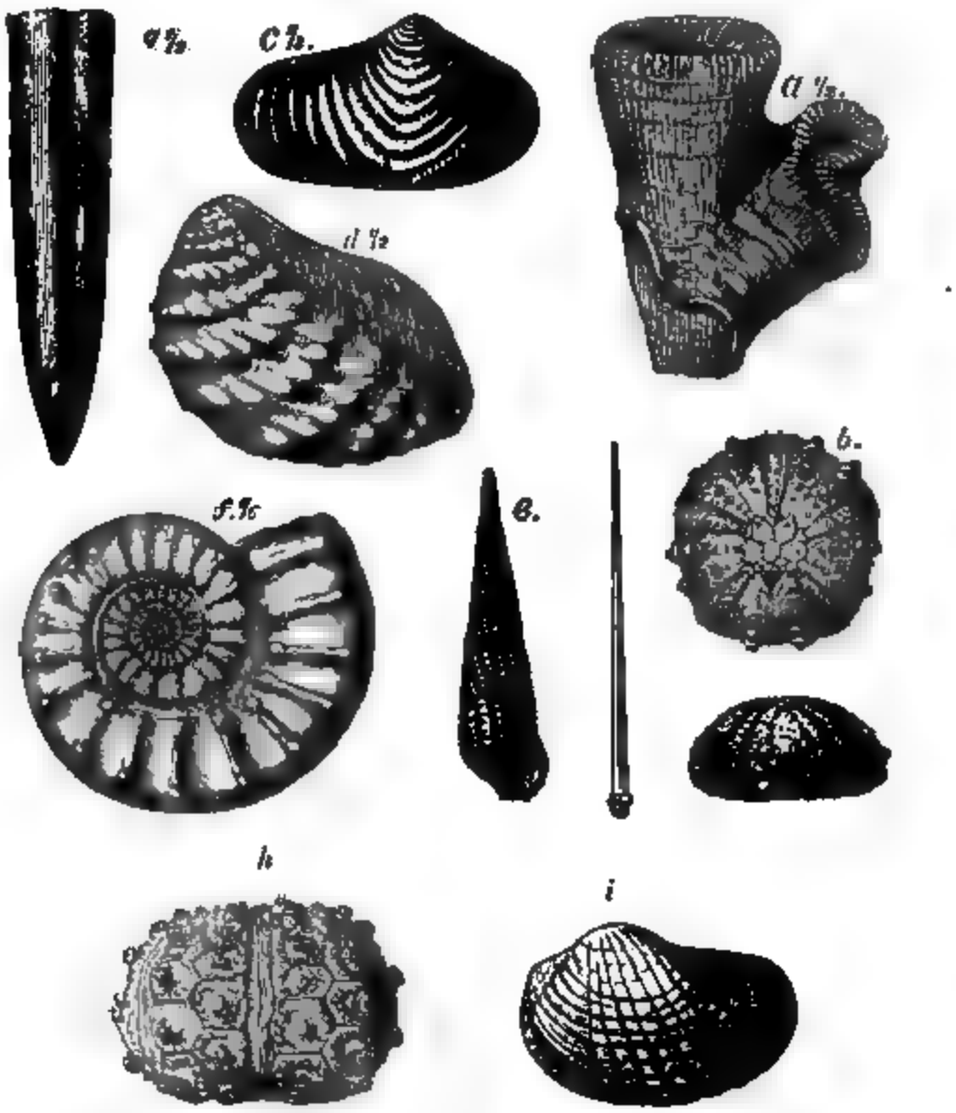

Fig. 120.—GROUP OF CORALLIAN FOSSILS.

a. Thecosmilia annularis.
b. Acrosulenia decorata.
c. Goniomya litterata.
d. Trigonia clavellata.
e. Cerithium muricatum.
f. Ammonites perarmatus.
g. Belemnites abbreviatus.
h. Cidaris florigemma.
i Pholadomya æqualis.

Echinoderma. Glypticus.
Lamellibranchia. Anisocardia, Mactra.
Gastropoda. Neritoma.
Cephalopoda. The Ammonite genera—Aspidoceras, Cardioceras, Craspedites, Hoplites, Oleostephanus, Peltoceras, Polyptychites, Ancyloceras : also Belemnoteuthis, Coccoteuthis, and Geoteuthis.

The following are some of the species which are specially characteristic of each member of the series:—

Fossils of the Oxfordian

Brachiopoda. Rhynchonella socialis, Waldheimia impressa.
Lamellibranchia. Gryphæa dilatata, Modiola bipartita, Pleuromya recurva, Anatina undulata, Nucula ornata.
Gastropoda. Alaria trifida, A. composita, Cerithium Damonis, C. muricatum.

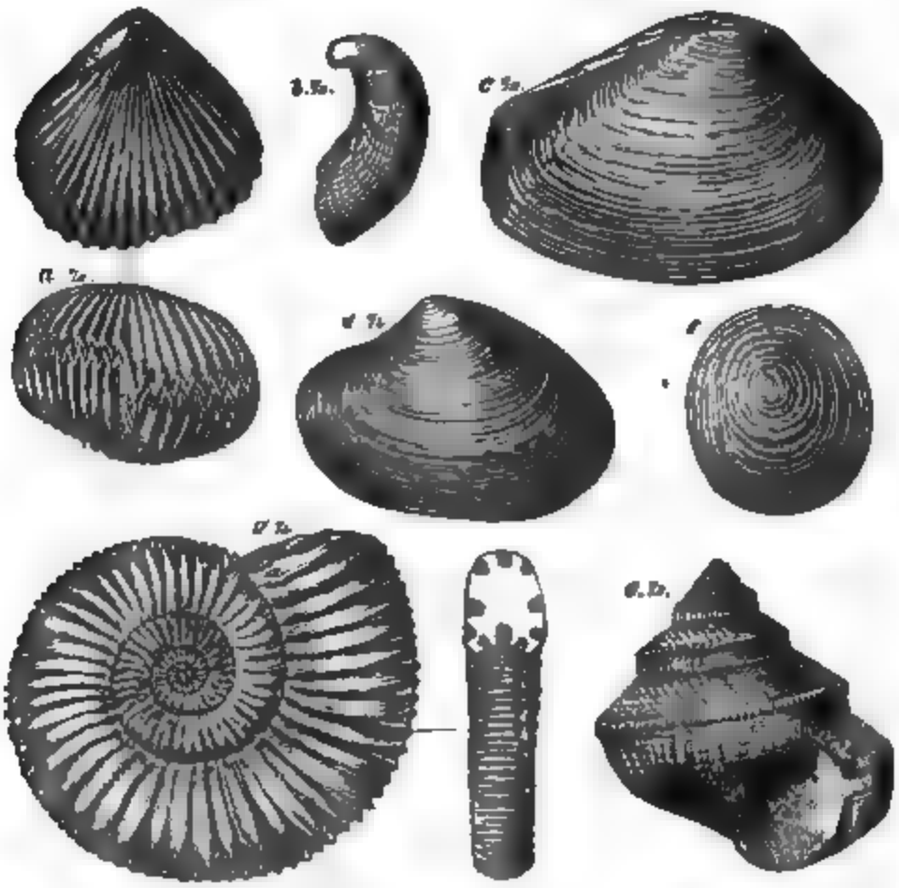

Fig. 121.—GROUP OF KIMERIDGIAN FOSSILS.

a. Rhynchonella inconstans.
b. Exogyra virgula.
c. Astarte hartivellensis.
d. Thracia depressa.
e. Pleurotomaria reticulata.
f. Orbiculoidea latissima.
g. Ammonites biplex.

Cephalopoda. Ammonites (Cosmoceras) calloviensis, Am. (Cosmoceras) jason, Am. (Cardioceras) Lamberti, Am. (Cardioceras cordatus, Belemnites hastatus, Bel. Oweni.
Fish. Leptolepis macrophthalmus.
Reptilia. Cimoliosaurus plicatus, Pliosaurus ferox.

Fossils of the Corallian Group

Actinozoa. Thecosmilia annularis, Thamnastrea arachnoides, Th. concinna, Isastrea explanata.

Echinoderma. Cidaris florigemma, Hemicidaris intermedia, Acrosalenia decorata, Nucleolites scutatus, Holectypus depressus.
Brachiopoda. Terebratula insignis, Waldheimia bucculenta.
Lamellibranchia. Gervillia aviculoides, Pecten articulatus, Ostrea gregaria, Goniomya litterata, Trigonia clavellata, Tr. perlata, Pholadomya æqualis.
Gastropoda. Cerithium muricatum, Bourguetia striata, Pseudomelania heddingtonensis, Nerinæa Goodhalli, Littorina muricata.
Cephalopoda. Ammonites (Aspidoceras) perarmatus, Am. (Perisphinctes) plicatilis, Belemnites abbreviatus.

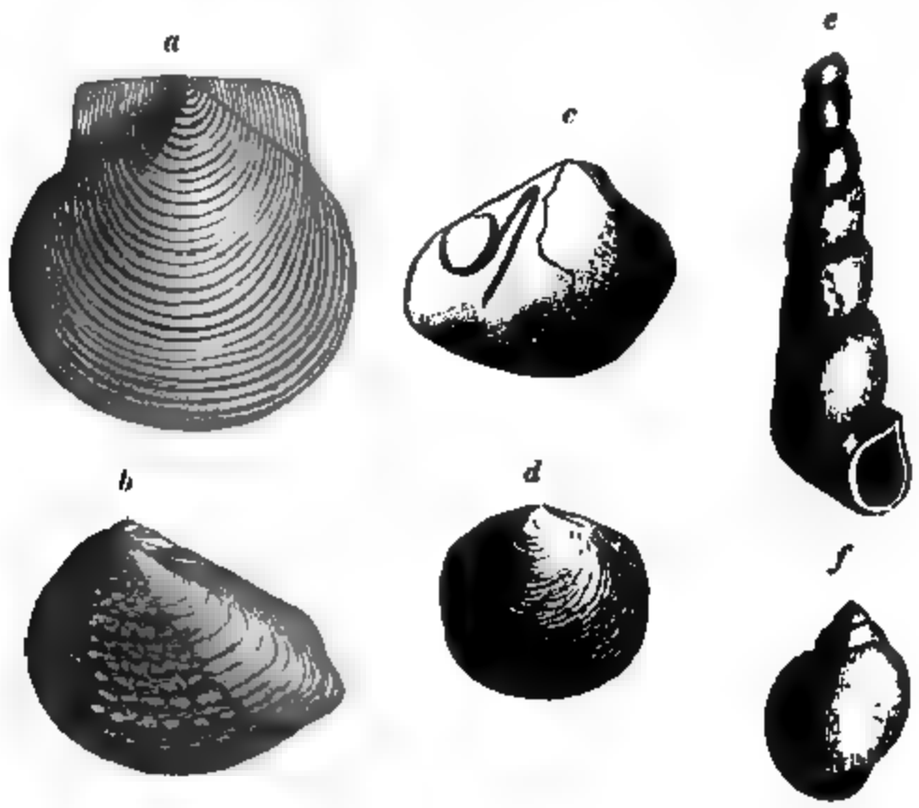

Fig. 132.—GROUP OF PORTLANDIAN FOSSILS.

a. Pecten lamellosus.
b. Trigonia gibbosa.
c. Protocardia dissimile.
d. Lucina portlandica.
e. Cerithium portlandicum.
f. Natica elegans.

Fossils of the Kimeridgian

Brachiopoda. Orbiculoidea latissima, Lingula ovalis, Rhynchonella inconstans.
Lamellibranchia. Ostrea deltoidea, Thracia depressa, Astarte hartwellensis, Trigonia monilifera, Protocardia striatula, Exogyra virgula.
Gastropoda. Pleurotomaria reticulata (also Oxfordian and Corallian), Littorina pulcherrima.
Cephalopoda. Ammonites (Perisphinctes) biplex, Am. (Cardioceras) alternans, Am. (Reineckia) endoxus, Belemnites nitidus.
Reptilia. Ichthyosaurus trigonus, Ich. enthecodon, Plesiosaurus trochanterius, Pliosaurus macromerus, Geosaurus maximus.

Fossils of the Portlandian

Actinozoa. Isastrea oblonga.
Brachiopoda. Waldheimia boloniensis.
Lamellibranchia. Protocardia dissimilis, Cytherea rugosa, Perna mytiloides, Pecten lamellosus, Trigonia gibbosa, Lucina portlandica, Ostrea expansa.
Gastropoda. Cerithium portlandicum, Neritoma sinuosa, Natica elegans, Pleurotomaria rugata.
Cephalopoda. Ammonites (Olcostephanus) giganteus, Am. (Perisphinctes) boloniensis.

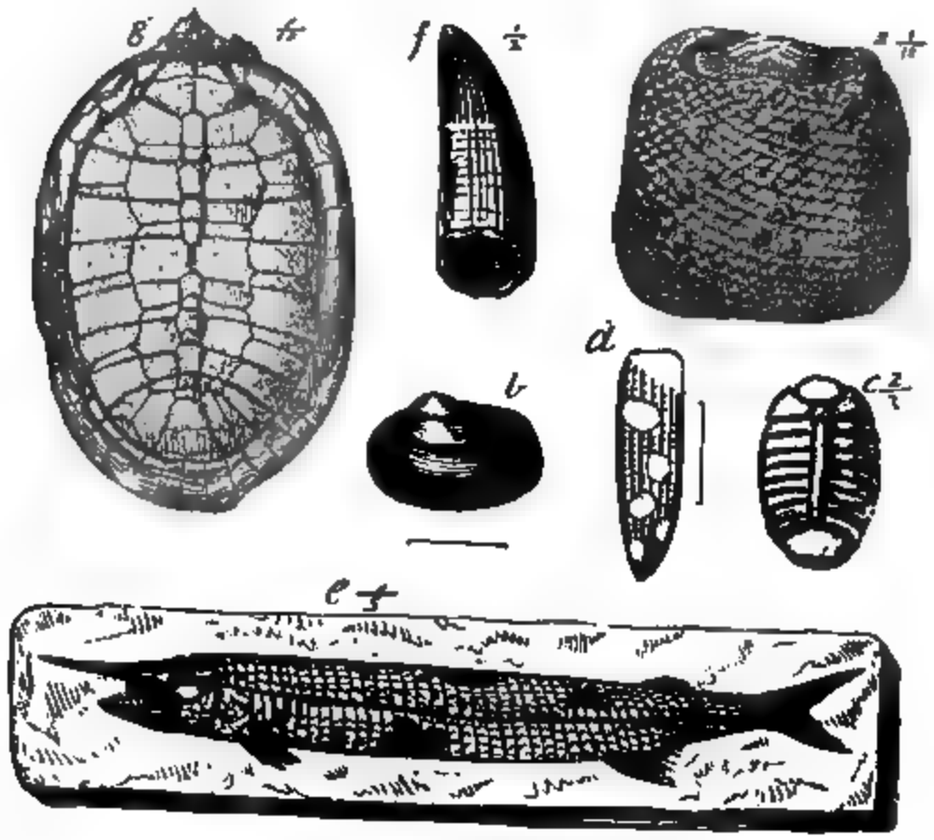

Fig. 123.—GROUP OF PURBECK FOSSILS.

a. Mantellia microphylla.
b. Cyrena elongata.
c. Archæoniscus Edwardsi.
d. Bupreston stygnus (elytron).
e. Aspidorhynchus Fischeri.
f. Goniopholis crassidens (tooth).
g. Pleurosternon ovatum (carapace).

Fossils of the Purbeck Beds

(*Estuarine, Freshwater, and Terrestrial*)

Plants. Mantellia nidiformis, M. microphylla, Chara Jaccardi.
Echinoderma. Hemicidaris purbeckensis.
Crustacea. Cypris purbeckensis, Cy. granulosa, Cy. punctata, Archæoniscus Edwardsi.
Lamellibranchia. Corbula alata, Cyrena media, C. elongata, Ostrea distorta, Unio valdensis.

Gastropoda.	Physa Bristovi, Viviparus carinifera, V. elongatus, Planorbis Fisheri, Melanopsis harpæformis.
Insecta.	Bupreston stygnus (a beetle), and many others.
Fish.	Lepidotus minor, Hybodus striatus, Microdon radiatus, Aspidorhynchus Fisheri.
Reptiles.	Goniopholis, Theriosuchus, Nannosuchus (Crocodiles), Chelone and Pleurosternon (Turtles), and Doratorhynchus (a Pterodactyle).
Mammalia.	Twelve genera and twenty species of Mammals, of which the more important are Plagiaulax, Bolodon, Spalacotherium, Triconodon, Stylodon, and Amblotherium.

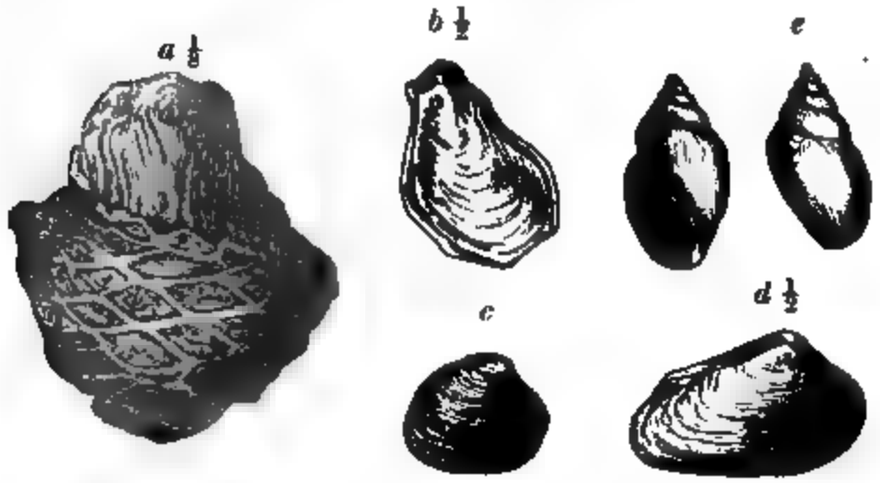

Fig. 124.—GROUP OF PURBECK FOSSILS.

a. Mantellia nidiformis.
b. Ostrea distorta.
c. Cyrena media.
d. Unio compressus.
e. Physa Bristovi.

STRATIGRAPHY

In the case of the Upper Jurassic rocks we need not divide their range through England into more than three sections or districts for separate consideration. The first we may call the southern district, the beds exposed in all the southern counties as far north as the neighbourhood of Thame and Aylesbury in Bucks belonging to one lithological type; the second, or central district, includes the counties of Bedford, Huntingdon, Cambridge, and Lincoln; the third, or northern district, contains the Yorkshire type.

1. *Southern District*

Oxfordian.—Lithologically this is divisible into two unequal parts: (1) the Kellaways Beds, which are a group of sands and clays with masses of calcareous sandstone, and (2) the Oxford Clay proper, which includes several hundred feet of blue and gray clays

with occasional layers of earthy limestone and of septarian nodules. Palæontologically it is divisible into four zones as follow in descending order :—

Zone of *Am. cordatus* } Blue clays with septaria.
,, ,, *Lamberti* }
,, ,, *jason*, gray shales with pyritic fossils.
,, ,, *calloviensis*, Kellaways beds.

The zones of *Am. jason* and *Am. Lamberti* are united by Mr. H. B. Woodward to form a zone of *Am. ornatus*, but as that is a rare species in the south of England, and the two zones can generally be recognised where there are sufficient exposures, it seems better to adopt them.

The Oxford Clay is well exposed in the cliffs near Weymouth, and the four zones have been recognised there by Mr. Woodward with a total thickness of about 500 feet ; the Kellaways Beds may be 60 or 70 feet, the two central zones about 180, and the *cordatus* zone 250 feet thick.

There are no good exposures in Somerset, but in Wilts the lower beds are traversed by the Great Western Railway near Trowbridge, and were described by Mr. R. N. Mantell. The same beds are exposed near Chippenham, and the higher zone of *Am. jason* seems to have been traversed in cuttings near Christian Malford (1841), whence many fine fossils were obtained, such as *Am. jason*, *Am. Elizabethæ*, *Belemnites Oweni*, and *Belemnoteuthis antiquus*.

The whole of the Oxford Clay was passed through by a boring at Swindon, where it was proved to be 572 feet thick, and the existence of the usual four zones is shown by the fossils obtained.[11]

Near Oxford the thickness of this stage is estimated at about 450 feet ; parts of it are seen in several brickyards, and, as was pointed out by Professor J. Phillips in his *Geology of Oxford*, there is evidence of the existence of the *jason*, *Lamberti*, and *cordatus* zones.

The Corallian Beds.—This stage was termed the "coral rag" by William Smith in 1815, from the abundance of corals in some of its beds, and it was subsequently divided by J. Phillips into a lower and upper "calcareous grit," with the "coralline oolite" between them. The name "Corallian" was proposed by d'Orbigny in 1849, and is now generally adopted as more convenient for the variable group of beds which intervene between the Oxford and Kimeridge clays. Two zones can be recognised, which can also be called the Lower and Upper Corallian, thus :—

Upper Corallian { Upper rags and grits, Coral rag limestones } Zone of *Am. plicatilis.*
Lower Corallian { Lower calcareous grit, Zone of *Am. perarmatus.*

In South Dorset the Corallian has a thickness of about 200 feet, but in North Dorset it is not more than 120, and thence northwards it varies from 80 to 100.

The Corallian is well exposed in the cliffs south of Weymouth, where local names have been given to the several members of the succession by Messrs. Blake and Hudleston, as below :—

		Feet.
Upper Corallian	Sandsfoot grits	15 to 25
	Sandsfoot clay	12 to 40
	Trigonia beds, shelly ragstones	12 to 16
	Osmington oolite, limestones, and marls	40 to 60
Lower Corallian	Bencliff grits, false-bedded sands	10 to 35
	Nothe clay, bluish sandy clays	30 to 40
	Nothe grits, calcareous grits, and marls	20 to 35

The Nothe grits and clays contain a mixture of Oxfordian and Corallian species—*Gryphæa dilatata*, *Ammonites cordatus*, *Ostrea gregaria*, and *Trigonia perlata*. The Osmington and *Trigonia* beds represent the coral rág, but corals are rare ; the rags contain *Trigonia clavellata*, *Gervillia aviculoides*, *Nerinæa Goodhalli*, *Am. plicatilis*, and many other fossils. The Sandsfoot clays and grits yield *Astarte supracorallina*, *Velopecten tumidus*, *Thracia depressa*, *Pholadomya hemicardium*, with *Ostrea deltoidea* and *Belemnites nitidus*, which range into the Kimeridge clay.

Near Abbotsbury the Sandsfoot grits pass into ferruginous sandstone and oolitic ironstone, the latter quarried as ore. Similar ironstone occurs at Westbury in Wiltshire, in which county the general succession is :—

			Feet.
Upper Corallian	Ironstone / Sands and clays	Upper calcareous grit	15 to 20
	Rubbly oolite and coral beds	Coral rag	20 to 30
	Calne freestone		20 to 50
Lower Corallian, sands with calcareous burrstones			50

The freestone thins out rapidly north of Calne, and is not present at Faringdon, where the Upper Corallian is not more than 20 feet thick. In Oxfordshire this stage consists of coral rag (30 to 40 feet) and lower calcareous grit (50 to 60 feet), the former consisting of coralliferous and shelly limestones, the latter of sands with calcareous burrstones. But near Stainton St. John these beds change rapidly and appear to be replaced by clays.

Kimeridgian.—This formation takes its name from Kimeridge Bay near St. Alban's Head in Dorset, where it has a thickness of no less than 1000 feet, and is divisible into two sub-stages—

	Feet.
The Upper Kimeridge or zone of *Ammonites biplex*	600
The Lower Kimeridge or zone of *Am. alternans*	400

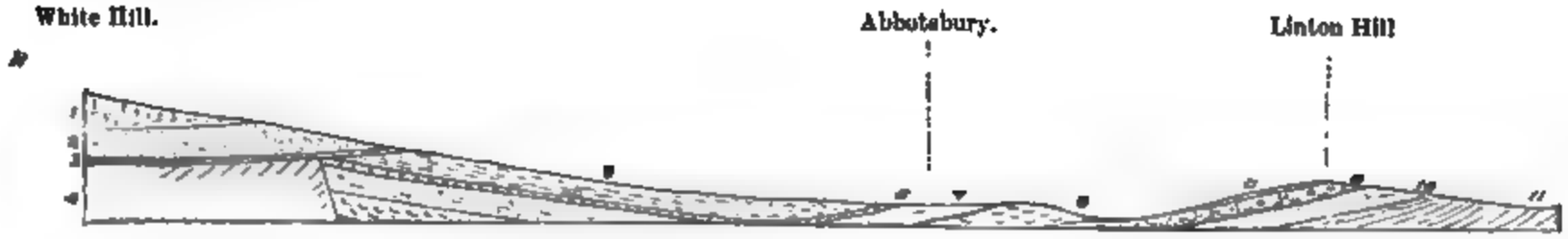

Fig. 125.—SECTION THROUGH ABBOTSBURY AND LINTON HILL IN SOUTH DORSET (after A. Strahan).

1. Chalk.
2. Upper Greensand.
3. Gault.
4. Forest Marble.
5. Kimeridge clay.
6. Abbotsbury ironstone.
7. Sandfoot beds.
8. Trigonia beds.
9. Osmington Oolite.
10. Lower Calcareous rock.
11. Oxford clay.
f. Fault.

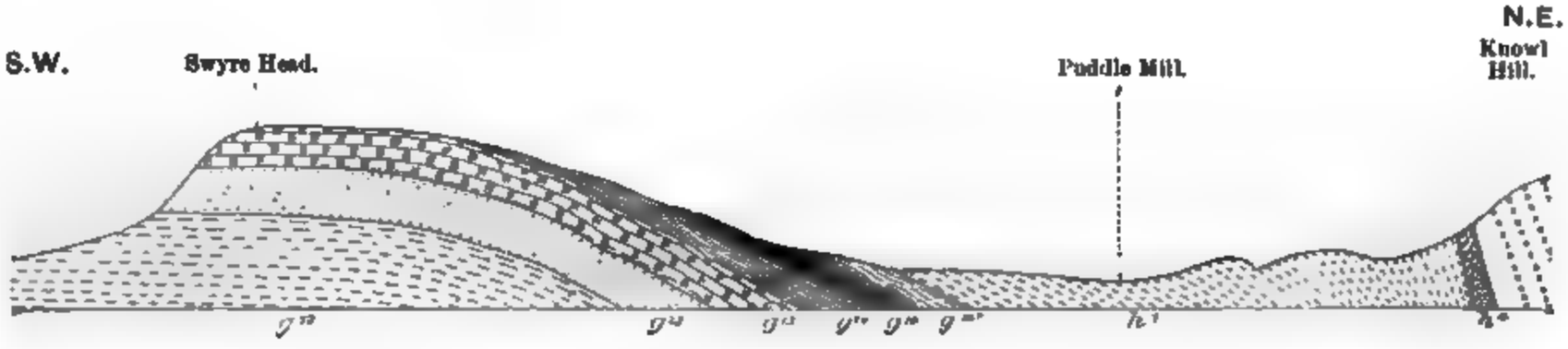

Fig. 126.—SECTION ACROSS THE MIDDLE OF THE ISLE OF PURBECK. Distance about 3 miles.

k^5. Chalk.
k^4. Selbornian.
g^{14}. Wealden Beds.
g^{14}. Purbeck Beds.
g^{13}. Portland beds.
g^{12}. Kimeridge clay.

In Dorset and Wilts the lower part consists of dark clays and shales with layers of septaria and cement stones; these beds yield *Am. alternans*, *Am. mutabilis*, *Ostrea deltoidea*, and *Rhynchonella inconstans*. The upper beds are black bituminous shales and gray papery shales, often full of broken and compressed shells; they yield *Am. biplex*, *Protocardia striatula*, *Thracia depressa*, *Exogyra virgula*, and *Lucina minuscula*. Reptilian bones occur throughout the Kimeridge clay, and among them are remains of two species of Pterodactyles.

There are few good inland sections of the Kimeridge Clay, and its thickness is greatly diminished in passing through Dorset and Wiltshire, for at Swindon it is estimated to be only about 300 feet.

In Berkshire and Oxfordshire it is not much more than 100 feet, but is still divisible into the two zones.

Portlandian.— Like the Kimeridge Clay, these beds are thickest in Dorset and thin northwards. They are well exposed between Durlstone Head and St. Alban's Head, where they are divisible as follows:—

		Feet.
Upper Portlandian or zone of *Am. giganteus*	Freestone beds	40 to 50
	Cherty beds	60 to 75
Lower Portlandian or zone of *Am. gigas*	Sandy marls, sands, and calcareous sandstone	130 to 160
		230 to 285

The hard sandy marls of the lower group contain *Am. biplex*, *Exogyra bruntutana*, *Trigonia incurva*, *Tr. Pellati*, and *Rhynchonella portlandica*. The "cherty beds" are brown earthy limestones with irregular layers and nodules of flinty chert; *Pecten lamellosus* and *Protocardia dissimilis* occur in these beds. The freestones are oolitic limestones, which are largely quarried for building stone, and the successive beds are locally known by different names, such as "curf," "whit bed," and roach"; they contain *Trigonia gibbosa*, *Perna mytiloides*, *Cerithium portlandicum*, and *Ammonites giganteus*.

At Portland the succession is similar, and the total thickness about 220 feet; but at Upwey, north of Weymouth, a different facies presents itself, the whole Upper Portlandian having passed into a white chalky limestone with black and gray flints. This is not more than 30 feet thick, while the sandy beds are about 60 feet, so that the whole is less than 100 feet. In the Vale of Wardour both chalky and oolitic limestones occur, and the general succession near Chilmark is as follows:—

		Feet.
Upper Portlandian	Buff oolitic limestone (upper freestone)	15
	Soft white chalky stone with flints	10 to 24
	Ragstones, brown shelly limestones	8
	Gritty and shelly limestones (lower freestone)	18
Lower Portlandian, brownish sands and clays		38
		About 100

The upper freestone contains *Trigonia gibbosa*, *Cytherea rugosa*, *Neritoma sinuosa*, and *Cerithium portlandicum*. The chalky beds have *Ostrea expansa*, *Pecten lamellosus*, and other fossils, and the ragstones yield many gastropods, such as *Natica elegans*, *Neritoma sinuosa*, and *Cerithium concavum*.

The next good section of the Portland group is at Swindon, where the limestones are partly replaced by sands. The beds are

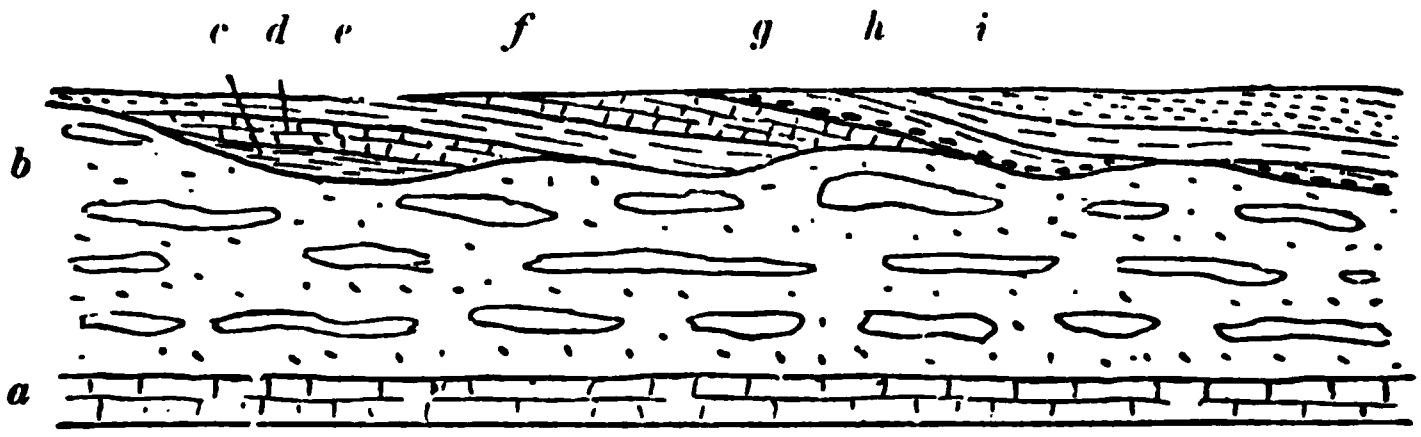

Fig. 127.—DIAGRAMMATIC VIEW OF THE SWINDON QUARRIES (after Professor J. F. Blake).

g, *h*, *i*. Purbeck beds.
c, *d*, *e*, *f*. Portland limestones.
b. Sand with calcareous doggers.
a. Portland limestone.

exposed in railway cuttings and quarries, and the combined succession is given by Mr. H. B. Woodward as follows:—

		Feet.
Upper Portlandian	Marly and oolitic limestones	6 to 12
	Whitish sands with lenticular layers of calcareous sandstone	20 to 25
	Marly and oolitic limestones with small pebbles at base	3 to 7½
Lower Portlandian	Blue clay weathering brown	14 to 20
	Marly sandstone with *Exogyra bruntutana*	6 to 8
	Sands with doggers of calcareous sandstone	30 to 40
		About 100

The uppermost limestones resemble those in the Vale of Wardour, and contain the same fossils, *Cerithium portlandicum* and *Trigonia gibbosa* being common.

Purbeck Beds.—The typical Purbeck Beds are only found where the Portland beds are completely developed, as in Dorset and the Vale of Wardour. They consist of limestones, shales, black

earths, and marls, in thin beds, which exhibit alternations of terrestrial, freshwater, brackish water, and estuarine conditions, the changes from brackish to freshwater deposits being generally gradual, while the reverse changes are abrupt, indicating sudden inroads of the sea.

In Durlston Bay, near Swanage, these beds are 400 feet thick, and have been divided into Lower, Middle, and Upper stages by Messrs. Forbes and Bristow, the following being a summary of the beds:—

		Feet.
Upper, 80 feet	Gray and purple marls with *Viviparus cariniferus*, not seen at Durlston Bay	14
	Shales with beds of Paludina limestone (Purbeck marble), *Cypridea* abundant	45
	Unio beds and shelly limestones with *Viviparus*	15
Middle, 155 feet	Alum-shales and thin limestones with layers of gypsum, *Corbula*, *Cyrena*, *Cyclas*, etc.	64
	Hard shelly limestones with partings of shale, fossils of marine and estuarine species	50
	Cinder bed, a mass of *Ostrea distorta*	9
	Thin limestones, marls, and shales with remains of insects, fish, and freshwater shells; at the base is a black shale with mammalian remains	43
Lower, 170 feet	Marly freshwater beds, *Physa* and *Planorbis*	7
	Marls and marly limestones with *Cardium*, *Corbula*, *Cyrena*, and *Cypridæ*	92
	Marly limestones and shales, with *Cypridæ*	36
	Beds of broken slaty limestone	15
	Brown bituminous limestones with a layer of dark earth (dirt bed) resting on Portland stone	19
		405

The same series can be seen in Worbarrow Bay, Mupes Bay, and Lulworth Cove, but become thinner to the westward, 250 feet at Mupes Bay, only 176 feet at Lulworth, and at Ridgeway Hill 190 feet. The Lower Purbeck is characterised by *Cypris purbeckensis*, the Middle by *Cypridea granulosa*, and the Upper by *punctata*.

The lowermost beds are well exposed in the quarries at Portland, where the most remarkable stratum is the upper "dirt bed," which is a dark brown loamy earth—an actual soil or terrestrial surface, in which cycads and coniferous trees are still rooted. It occurs about 11 feet from the base, and its thickness is not more than a foot.

The Purbeck Beds are cut off and faulted against the Chalk and Greensand by the great Ridgeway fault, and they are not seen again till they crop out in the Vale of Wardour (Wilts). The succession in this area, as described by Mr. W. R. Andrews and

myself in 1894,[12] with such subsequent corrections by Mr. H. B. Woodward [13] as we accept, is as follows :—

		Feet.
Upper	Clays, marls, and shelly limestones with *Cypridea punctata*, *Cyrena media*, and *Unio*	10
	Yellow sand and gray clay	12
Middle	Sandy and marly limestones, shelly marls, and cinder bed with *Ostrea distorta* and *Trigonia gibbosa* . .	12
	Limestones and shelly marls, *Cypridea granulosa* .	11
Lower	Marly limestones (locally known as Lias) with layers of shaly marl, *Cypris purbeckensis*	20
	Pale yellow oolitic limestones and marls . . .	25
	Gray laminated marls and limestones	20
	Total about	110

The lower beds are well exposed at Wockley, and the passage from Portland to Purbeck conditions takes place in a bed of limestone about 2 feet thick, the lower part of which is a chalky limestone with marine fossils, and the upper part a flaggy limestone with estuarine Cyprids (*Cypris bononiensis* and *Candone ansata*). At Chilmark, however, the junction is very different and is like that in Dorset, a thin seam of dark clay resting directly on the Upper Portland freestone, which is absent at Wockley, unless represented by the 2 feet of limestone above mentioned.

The Lower Purbeck is seen again at Swindon, resting unconformably on the Portlandian, the basement bed being a rubbly marl enclosing rolled lumps of limestone. The thickness seen, however, is only about 18 feet.

2. *Central District*

In this part of England, from near Quainton in Bucks to the estuary of the Humber, a broad mass of clays intervenes between the outcrop of the Cornbrash and the base of the Cretaceous series, beds of Portland and Purbeck age being only found near Aylesbury. This mass of clay is divisible as follows :—

	Bedford.	Lincsh.
Kimeridge clay	120	300
Ampthill clay (=Corallian)	60	20
Oxford clay	500	300

Oxfordian.—This is, of course, a continuation of the Oxfordian Beds described on p. 376. The Kellaways Beds are exposed in quarries and cuttings near Bedford, and have yielded *Ammonites gowerianus*, *Ancyloceras calloviense*, *Belemnites Oweni*, *Gryphæa bilobata*, and *Pleuromya recurva*. Near Huntingdon and St. Ives there are

good exposures of the clays, which here include many bands of earthy and sandy limestone. At St. Neots the beds exposed belong to the zone of *Am. jason*, while those at St. Ives below the St. Ives rock belong to the zone of *Am. cordatus*.

Professor Judd recognised the following sequence north of Huntingdon :—

5. Clays with *Am. cordatus*.
4. Clays with *Am. ornatus* and *Am. Duncani*.
3. Clays with *Bel. hastatus* and *Bel. Oweni*.
2. Shales with *Nucula nuda* and *Am. jason*.
1. Kellaways sands and clays.

Near Peterborough the clays of No. 3 have yielded ten species of reptiles and five of fish. The Oxford clay borders and underlies the western part of the Fen district, emerging on the north side of the river Witham near Bardney, and passing northward to the valley of the Ancholme, which drains into the Humber.

Corallian.—In Bucks and Bedfordshire this stage is represented by the Ampthill Clay, named from the small town of Ampthill. This clay contains a mixture of species belonging to the Oxford and Kimeridge clays with a few that are more especially Corallian. The chief Ammonites are *achilles*, *cordatus*, *plicatilis*, and *vertebralis;* with these are found *Alaria bispinosa*, *Exogyra nana*, *Ostrea deltoidea*, *O. discoidea* (allied to *deltoidea* but more circular), *Gryphæa dilatata*, *Cidaris florigemma*, and *C. Smithi*. As seen near Ampthill this division consists of gray marly clay with selenite and a band of septaria at the top and a bed of nodular limestone 4½ feet thick at the base.

At Elsworth, between Cambridge and St. Ives, there are two beds of dark gray ferruginous limestone which are now regarded as equivalent to the lower calcareous grit, and are overlain by clay of the Ampthill type. Similar limestone occurs at St. Ives and Upware, and these beds have yielded some typical Corallian fossils such as *Holectypus depressus*, *Collyrites bicordata*, *Terebratula insignis*, *Waldheimia bucculenta*, *Trigonia perlata*, and *Pholadomya æqualis*.

At Upware, between Cambridge and Ely, there is an isolated mass of undoubted Coral Rag and Coralline oolite, which seems to be part of a true coral reef. One pit exposes coral limestone, with *Thamnastrea arachnoides* and *Isastrea explanata*, *Cidaris florigemma*, *Opis*, *Plicatula*, *Lithodomus*, and other inhabitants of the reef ; while another pit is opened in soft yellowish oolite, without corals, but containing *Nucleolites scutatus* and *Holectypus depressus*. This coral reef is not of large extent, for no such rock was found in a boring 2½ miles north-west of Upware, which traversed the following beds as identified by Mr. T. Roberts :[14]—

	Feet.
6. Alluvial deposits (peat and sand)	8
5. Lower Greensand	13
4. Kimeridge clay with *Am. alternans* . . .	51
3. Ampthill clay	26
2. Elsworth rock and brown sandstone . . .	19
1. Oxford clay (clays and limestone bands) . . .	81
	199

The Ampthill clay was recognised by Mr. Roberts in Lincolnshire.[15] It forms a narrow band between the Oxford and Kimeridge clays from Bardney on the Witham to Briggs and Wrawby, and it yields the same fossils as in Bedford and Cambridge. Its thickness is not less than 20 feet, and may be more.

Kimeridgian.—Near Aylesbury the Kimeridge Clay is not more than 100 feet thick, and merges upward into a sandy clay containing Portlandian fossils (the Hartwell clay). Near Leighton Buzzard, and thence through Bedfordshire, most of the Kimeridge Clay is concealed by the Cretaceous sands, and does not emerge again till we reach the neighbourhood of Papworth in Cambridgeshire, where it appears above the Ampthill Clay, and runs in a narrow belt by Knapwell, Boxworth, and Cottenham to the Fens. Its base was exposed in Knapwell brickyard, and is marked by a layer of phosphatic nodules resting on the Ampthill clay. A similar layer of nodules marked the base in the boring at Chittering above mentioned.

Near Ely this clay has been largely dug, and both zones (upper and lower) have been recognised. The lower (from 80 to 90 feet) contains *Am. alternans*, *Astarte supracorallina*, *Ostrea deltoidea*, etc.; the upper, of which only 16 feet is seen, contains *Exogyra virgula* and *Orbiculoidea latissima*, but still higher beds may be concealed beneath the Cretaceous rocks.

In Lincolnshire both lower and upper divisions are well developed, and the whole stage is probably about 600 feet thick. The lower beds are exposed near Horncastle, Wragby, Market Rasen, and Wrawby near Caistor. At Rasen it yields many finely preserved fossils, which include *Ammonites alternans*, *Am. mutabilis*, *Trigonia Juddiana*, *Inoceramus rasenensis*, *Thracia depressa*, and *Nucula Menkei*. The upper beds are mainly shales, seen near Spilsby, Fulletby, and West Ashby, and yielding *Am. biplex*, *Protocardia striatula*, *Lucina minuscula*, *Lingula ovalis*, and *Orbiculoidea latissima*.

Portlandian.—These beds are well exposed near Thame, Brill, and Aylesbury, where they exhibit a special facies different from that of Dorset or Wiltshire. The complete succession, as gathered from several quarry sections, is stated as follows:—

		Feet.
Upper Portland, 26 feet	Brown sandy marl and hard limestone, *Am. giganteus*, *Ostrea expansa*, and *Trigonia* . . .	0 to 2
	Marly and shelly limestones, *Trigonia gibbosa* . .	5 to 8
	Greenish yellow sand	5 to 6
	Marly and rubbly limestone with fossils . . .	10 to 15
	Yellowish green sand with a bed of small pebbles of quartz and lydianite at the base	8 to 10
Hartwell Clay	Fine sandy clay with *Astarte hartwellensis*, *Cardium morinicum*, *Perna Bouchardi*, *Trigonia Pellati* .	20 to 30
		About 60 feet

Here it would seem that the Portland Sands are replaced by the Hartwell Clay. The most northerly outlier of these beds is at Stewkley Warren, 4 miles west of Leighton Buzzard, where about 15 feet of them, capped by a few feet of Purbeck Beds, was at one time exposed.

Beyond this they are not seen either in Bedford, Cambridge, Norfolk, or Lincoln, but derived and phosphatised Portlandian fossils are of frequent occurrence in the Lower Cretaceous sands, and consequently it is most probable that they originally extended through these counties, but were destroyed at the beginning of the Cretaceous period.

Purbeck Beds.—In the neighbourhood of Thame, Aylesbury, Brill, and Whitchurch the Portland Beds are succeeded by a variable group of beds with freshwater fossils, which are generally considered to be of Purbeck age. They consist of a variable series of thin-bedded limestones, marls, shales, clays, and Calcareous sands, and do not exceed 30 feet in thickness. They have yielded remains of plants, insects, cyprides, with *Viviparus*, *Cyrena*, *Modiola*, and the following fish, *Lepidotus minor*, *Pleuropholis serrata*, *Aspidorhynchus*, and *Mesodon*.

3. *Northern District*

In the north of Yorkshire representatives of all the Upper Jurassic groups come in again, with the exception of the Purbecks, and are well exposed along the coast near Scarborough.

Oxfordian.—Succeeding the Cornbrash are 10 or 12 feet of shale, with *Pseudomonotis echinata*, which are grouped with the Cornbrash by Hudleston, and with the Kellaways by Etheridge. The Kellaways Rock where first appearing is only 9 feet thick, but in Gristhorpe Bay it is 24 feet, and at Scarborough, 5 miles to the north-west, there are no less than 76 feet of sandstone. It seems, however, that only the lower 62 feet of this belong properly to the Kellaways, for the highest beds contain *Gryphæa*

dilatata and Ammonites of the *Ornati* group, which characterise the lower part of the Oxford Clay elsewhere. Above this sandy zone are gray sandy shales 120 feet thick, containing *Am. Lamberti*, *Am. cordatus*, *Am. crenatus*, and other fossils. Westward both shales and sands decrease in thickness, and are only 80 feet thick in the Howardian Hills.

Corallian Group.—This attains an unusual thickness in Yorkshire, and occupies a large area of ground round the Vale of Pickering. It has been specially studied by Messrs. Blake and Hudleston, and by Mr. Fox-Strangways, from whose memoir the following tabular view of the succession near Pickering has been taken :—

		Feet.
Zone of *Am. plicatilis.*	Upper Calcareous Grit, shales, and grit with *Am. alternans*, *Belemnites nitidus*, and *Goniomya literata* .	30 to 40
	Upper limestones, coral rags, and oolites with *Am. plicatilis*, *Bourguetia striata*, *Trigonia perlata*, *Cidaris florigemma*, *Thamnastrea concinna*, and other corals	40 to 50
	Middle Calcareous Grit with *Am. plicatilis*. . .	40 to 80
Zone of *Am. perarmatus.*	Lower limestones with *Am. cordatus* and *Nucleolites scutatus*	30 to 60
	Graystones, coarse, gritty, and cherty limestones with *Am. goliathus*, *Gervillia aviculoides*, and *Rhynch. Thurmanni*	25 to 40
	Lower Calcareous Grit, gritty limestones, and soft calcareous sandstone, with *Am. perarmatus*, *Rhynchonella Thurmanni*, and *Collyrites bicordatus* . . .	50 to 130
		From 215 to 400

Kimeridgian.—The Kimeridge Clay is not well exposed in Yorkshire, for though it doubtless underlies a large part of the Vale of Pickering, it is concealed by glacial drifts, and only the highest beds are exposed on the shore at Speeton Gap. These consist of brown and black shales containing *Am. biplex* (?), *Ostrea gibbosa*, *Discina latissima*, and *Lingula ovalis*.

Westward towards Malton borings show a thickness of more than 400 feet of shales and clays, and the basal clays are exposed in a brickyard at Hildenley, where they yield *Am. mutabilis*, *Ostrea deltoidea*, and *Thracia depressa*. South of Malton it is traceable along the steep frontal slope of the Wolds till it is lost under the overlap of the Cretaceous strata near Acklam.

Portlandian.—At Speeton the Kimeridge Clay is surmounted by a bed of black phosphatic nodules, the "coprolite bed," and the clays above this contain Ammonites which resemble Portlandian species, so that the beds have been classed by some as Portlandian. As, however, the Ammonites are not identical with Portlandian forms, and as the Neocomian Belemnite (*B. lateralis*) occurs

throughout with *Am. regalis* in the higher part, the beds are probably of Lower Cretaceous age (see p. 418).

4. *Scotland*

West Coast.—The only member of the Upper Jurassic series which is found on the west coast of Scotland is the Oxford Clay. This overlies the great estuarine series in the islands of Skye and Eigg, and consists of blue clays containing *Ammonites cordatus*, *Am. excavatus*, *Am. Lamberti*, and others. Above it are Cretaceous rocks.

East Coast.—In Sutherland a much more complete series is found; the beds are seen at intervals along the coast for a distance of 16 miles, and form a narrow strip of low ground, which is bounded inland by a powerful fault, and the extreme width of which near Brora is about 2 miles. In this small space is found a succession of beds representing the whole of the Oxford Clay, Coral Rag, and part of the Kimeridge Clay, as below :—

		Feet.
Kimeridge Clay	Light-coloured sandstone; no fossils	100
	Shelly limestones, black shales, and grits with *Bel. abbreviatus*, *Am. alternans*, *Am. biplex*, and many others; ferns, cycads, and conifers	500
	White sandstones and carbonaceous shales; estuarine beds with few fossils	200
	Grits and sandstones; *Am. biplex*, *Am. eudoxus*, *Am. mutabilis*, and *Bel. obeliscus*	? 200
Corallian	Gray limestones and sandy clays in two bands, separated by 60 feet of white sandstone; *Am. cordatus*, *Am. excavatus*, *Trigonia corallina*, and other coral rag species	? 150
	White sandstones with bands of lignite and occasional layers containing casts of marine shells; estuarine beds	400
	White cherty sandstone with many fossils, *Am. perarmatus*, *Am. achilles*, etc. (lower calcareous grit)	25
Oxfordian	Sandy clays and black shales with *Bel. Oweni*, *Bel. hastatus*, *Am. ornatus*, *Am. Duncani*, etc., etc.	300
	Sandy shales, with *Nucula nuda*, *Am. gowerianus*, and *Am. callovicnsis*	5
	Calcareous sandstone with many fossils, fauna of Kellaways Rock	5

Physical Geography of the Jurassic Period

1. **Lower Jurassic Time.** — The physical geography of the Liassic epochs was a simple and direct modification of that which prevailed during the preceding Triassic period. No local

elevations and subsidences took place in the British area, for the Rhætic and Liassic beds occupy the same basins of deposit as those which hold the Keuper marls; the great lakes or inland seas in which the latter were accumulated became by submergence the seas and bays in which the shales and limestones of the Lias were laid down.

All the central and southern part of England was covered by the sea, but there was a large area of land to the east of our islands, and a portion of this extended into the east of England, though the trend of its coast is quite uncertain. About the land on the west we have more information; it was probably continuous from the north of France through Cornwall, Devon, Wales, and Ireland; the sites of the English, Bristol, and Irish Channels seem to have been bays or gulfs running up into this land, and these channels then narrowed westward, opening into an eastern, and not a western sea as they do now. As to the Irish Channel we have no certain information, but if a gulf then existed on its site it doubtless opened northward and narrowed southward. The Mendip Hills formed an island at the mouth of the gulf that separated Devon and Wales.

The greater part of Scotland seems to have been land which projected southward through the north of England and along the Pennine chain, dividing the sea-space into two great gulfs—one extending north-eastward into what is now the North Sea, and the other stretching westward into Ireland, and thence northward along the western coast of Scotland to Mull, Skye, and Raasay.

The chief difficulty in the restoration of Liassic geography is the manner in which the sea penetrated to the north-east of Scotland. It has been supposed that open sea extended northwards from Yorkshire outside the east coast of Scotland, and that from this sea a bay reached westward into Sutherland; but this theory carries an eastern sea for 200 miles over a space where there is no evidence of its existence, and the estuarine character of the beds which overlie the Lias in Yorkshire make it probable that the eastern gulf terminated in the estuary of a large river. Hence it seems more likely that the Moray and Sutherland basin was connected south-westward across Scotland with the gulf which unquestionably extended to the west coast within 70 miles of Dunrobin Castle.

The deposition of so great a thickness of dark-coloured clay and shale in Liassic times calls for explanation, and it may be fairly assumed that this material was mainly supplied by the destruction of the Carboniferous shales. Large tracts of Coal-measures and of Lower Carboniferous shales must have existed at this time both in

Ireland and Scotland, and the rivers flowing off these tracts would pour little else than black mud into the surrounding sea, while the waves would eat deep into such portions as came within their reach during the gradual submergence.

2. **Middle Jurassic Time.**—The physical geography of the British Islands during this part of the Jurassic period does not seem to have differed much from that which prevailed during Liassic times. The same general arrangement of sea and land which has just been described continued during the formation of the Oolites, though certain important changes and modifications of the coast-line seem to have taken place, otherwise it would be difficult to explain the complete change in the character of the sediment laid down—the change from the dark shales of the Lias to the sands, marls, and oolitic limestones of the newer series.

At first sight nothing seems easier to explain than such a change; a clay succeeded by a limestone seems to point to a general depression, whereby the extent of the sea was enlarged and its depth increased, but it is a mistake to suppose that all limestones are deep-water formations, and oolitic limestones in particular are generally of shallow-water origin, for such limestones are at the present day formed principally in the neighbourhood of coral reefs. Again, if the Coal-measures were, as above suggested, the source of the mud composing the Lias, the supply of this might be cut off by elevation as completely as by submergence. Moreover, in the Midland counties of England we have distinct evidence of the close proximity of land throughout the Middle Jurassic period; and finally, in Yorkshire and on both sides of Scotland we find estuarine and freshwater conditions prevailing largely throughout the Middle Jurassic series.

On the other hand, we must remember that the Great Oolite overlaps the Inferior Oolites and the Lias till it rests on the older rocks below Richmond and London. Hence, while there seems to have been elevation of the northern and north-western districts, there seems to have been continued subsidence in the southern and south-eastern districts. The movement, therefore, must have been a tilting one, like that which affected Norway and Sweden in recent times.

Confining our view to the sea which lay over the southern and midland counties at this time, we may picture it as lying between the mountainous region of Wales and Devon on the one hand, and the land which is now buried beneath our eastern counties on the other hand. Southward it doubtless opened into a wider sea through which came currents of warm water from equatorial regions, imparting a high temperature to the British shores, and

enabling reef-building corals to flourish where other conditions were favourable to their existence.

In this sea flourished an immense number of marine creatures, coral reefs were formed from time to time, and their *debris* afforded the material for the oolitic limestones which now furnish such valuable building stones. On the surrounding land grew magnificent ferns and cycads, with coniferous trees on the higher ground, but so far as we know the only vertebrate denizens of the region were small Marsupials, huge Dinosaurian reptiles, the bat-like Pterodactyles, marine crocodiles, and a variety of fish.

The country which now exhibits the nearest approach to such a scene is Australia and its neighbouring islands. There many of the Jurassic types still survive. The indigenous Mammalia are all Marsupials and *Prototheria* ; the plants include ferns, cycads, and Araucarian pines. Coral reefs fringe the shore, and in the waters are Cestraciont fish and many of the same Molluscan genera as are found in the Oolites, viz. *Phasianella*, *Stomatia*, *Trigonia*, *Corbis*, with others that have a wider distribution, and the Brachiopod *Waldheimia* is common in Torres Straits. There are, however, no survivors of the Jurassic reptiles, nor of the Ammonites and Belemnites which swarmed in the older seas.

3. **Upper Jurassic Time.**—From the stratigraphical facts recorded in the foregoing pages we may draw two conclusions with regard to the physical conditions under which the Upper Jurassic rocks were deposited. The first inference is that the seas of the Oxford and Kimeridge clays were much deeper and more extensive than the reef-blocked sea of the Middle Jurassic times. Secondly, we infer that this sea again became shallower, partly by deposition and partly by upheaval, during the Portland and Purbeck times, till eventually the greater portion of it was raised into dry land.

If further testimony to the shallowness of the Great Oolite waters were needed, the scarcity of Ammonites in the rocks of that group would supply it, only three species being known to occur in the Forest Marble and Cornbrash. The sandy nature of the Kellaways Rock precludes us from supposing it to have been a deep-water deposit, but its fauna indicates that deep water was not far off, for in these beds a large number of new Ammonites suddenly make their appearance, and most of them continue in the Oxford Clay. The change from Cornbrash to Kellaways Rock is particularly striking in Yorkshire, where the latter contains no fewer than forty-one species of Ammonites, and only one is common to the two deposits ; twenty of these species pass up into the Oxford Clay.

The existence of Oxford Clay with marine fossils on both sides of the northern part of Scotland is a further proof of the general subsidence, and in this widespread deposit of dark blue clay we seem to have a repetition of Liassic conditions, in so far that the rivers which drained the surrounding land were enabled to carry down an enormous quantity of dark-coloured mud.

When, however, we endeavour to form some idea of the geography of this part of the period we are faced with the difficulty that we have little evidence to guide us with respect to the eastward extension of the Upper Jurassic series. From the fact of its being fully developed in Hanover, it seems very probable that a communication was now established between the English and Germanic seas, but it is very doubtful whether the Scoto-Scandinavian land was broken through. There is, at any rate, no necessity for imagining a sea between Scotland and Norway merely to account for the Upper Jurassic of Sutherland and of Franz Joseph Land in the Arctic region.

The period closed with a general upheaval of the whole region, the sea became shallower and clearer, so that limestones (Portlandian) were again formed in restricted areas. Finally, a large part of the sea-floor was raised into dry land, the seas were contracted into narrow limits, and that over the south of England was reduced to an estuarine lagoon, in which the Purbeck Beds were deposited.

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[1] The "Jurassic Rocks of Britain," vol. iii. (Lias) p. 117, by H. B. Woodward, *Mem. Geol. Survey* (1893). [1a] *Op. cit.* p. 222.

[2] See the "Jurassic Rocks of Britain," vol. i. (Yorkshire), by C. Fox-Strangways, *Mem. Geol. Survey* (1892).

[3] J. W. Judd on the "Secondary Rocks of Scotland," Part II. *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 660 (1878).

[4] J. W. Judd, *Ibid.* Part I. *op. cit.* vol. xxix. p. 98 (1893).

[5] The "Jurassic Rocks of Britain," vol. iv. (Lower Oolites), by H. B. Woodward, *Mem. Geol. Survey* (1894).

[6] S. S. Buckman in *Quart. Journ. Geol. Soc.* vol. xlix. p. 485 (1893), and *Monograph of the Inferior Oolite Ammonites*, Part I. p. 5 *et seq.* Palæont. Soc. (1886).

[7] E. A. Walford in *Quart. Journ. Geol. Soc.* vol. xli. p. 38 (1885).

[8] See "Geology of Rutland," by J. W. Judd, *Mem. Geol. Survey* (1877), and "Geology of S.-W. Lincolnshire," by A. J. Jukes-Browne, *Mem. Geol. Survey* (1885).

[9] Consult Fox-Strangways in *op. cit.* (No. 2).

[10] See J. W. Judd in *op. cit.* (No. 3).

[11] H. B. Woodward in *Quart. Journ. Geol. Soc.* vol. xlii. p. 287 (1886), and "Jurassic Rocks of Britain," vol. v. p. 37, *Mem. Geol. Survey* (1895).

[12] See *Quart. Journ. Geol. Soc.* vol. l. p. 44 (1894).

[13] In the "Jurassic Rocks of Britain," vol. v. p. 273.

[14] *Jurassic Rocks of Cambridge*, by T. Roberts (Camb. Univ. Press, 1892) pp. 23, 47, 65.

[15] See Roberts in *Quart. Journ. Geol. Soc.* vol. xlv. p. 556 (1889).

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CHAPTER XV

THE CRETACEOUS SYSTEM

THIS system takes its name from *creta*, the Latin word for chalk, because this well-known rock forms a conspicuous part of the system in Western Europe. Beneath the chalk, however, there is a variable series of marine sands and clays, and below these in the south of England there is a great thickness of freshwater deposits which have long been known as the *Wealden*, from the large area occupied by them in the Weald of Kent and Sussex. In the British area it is only in Yorkshire and Lincolnshire that marine deposits of the same age as the Wealden are found, but in other parts of Europe they attain a great thickness.

The system is divisible into two great series, a lower and an upper, and the following table shows the subdivisions which have been adopted for the rocks of the southern counties; this nomenclature, however, is not applicable to the lower series in Lincolnshire and Yorkshire.

		Max. Thickness. Feet.
Upper Cretaceous	Upper Chalk (Senonian)	1200
	Middle Chalk (Turonian)	260
	Lower Chalk (Cenomanian)	250
	Upper Greensand and Gault (Selbornian)	300
Lower Cretaceous	Lower Greensand (Vectian)	800
	Weald clay, Hastings sand } Wealden	2000

As the greater part of the Lower Cretaceous series in the south of England is of freshwater origin, and as the highest part of the Chalk is nowhere visible, it is desirable that the student should be acquainted with the continental succession, which presents a much more complete marine series of Cretaceous deposits than is found in Southern England. In the following table we give the stages now generally accepted in Western Europe and their equivalents in Southern and Northern England:—

Western Europe.	Southern England.	Northern England.
Danian . . .	Wanting . .	Wanting.
Senonian . .	Upper Chalk . .	Upper Chalk.
Turonian (restricted)	Middle Chalk .	Middle Chalk.
Cenomanian . .	Lower Chalk . .	Lower Chalk.
Albian . . .	Selbornian . .	Red Chalk.
Aptian . . .	Vectian . . .	Upper Speeton clay.
Barremian } Neocomian } . .	Wealden . .	Middle and Lower Speeton clay.

The relation of the Cretaceous strata to the underlying formations is an important matter. Throughout the greater part of England there is a marked break and unconformity between the Jurassic and Cretaceous systems, and even in Yorkshire the apparent conformity is probably deceptive, for there is nothing there which can safely be correlated with the Portlandian, and it is very doubtful whether there is any representative of the Purbeck Beds. It is only in the south of England, where the highest Jurassic beds are fully developed, that a complete sequence of deposits is found to fill up the gap between the two systems, but these deposits are of freshwater origin and do not bridge over the gap in the marine succession.

This gap was undoubtedly caused by the elevation of the greater part of the British region into dry land, land which extended southward into France and eastward through Belgium, and it was only after a long period of time, marked by the formation of several thousand feet of marine deposits in the south of France, that parts of this land were again submerged and that marine deposits were laid down all across England. This change was the commencement of a great subsidence which eventually carried the Cretaceous seas over the greater part of Europe.

As a consequence of this continued subsidence we find the higher members of the Cretaceous system spread far beyond the areas occupied by the lower beds. Thus along the south coast of England the Selbornian clays and sands overlap the Vectian or Lower Greensand, and overstep the successive members of the Jurassic series to the westward, passing from the surface of the Lower Oolites on to the Lias, and from the Lias on to the Trias, till at length outliers of the Upper Greensand rest directly on the lower part of the Permian in Devon, and there can be little doubt that they passed from this onto the surface of the Carboniferous and Devonian rocks, and were banked up against the granite of Dartmoor.

A similar overlap and overstep takes place in the Midland counties, the Lower Cretaceous beds being overlapped by the Gault, which passes across the edges of the Purbeck and Portland

Beds till, in Buckinghamshire, it rests upon the Kimeridge clay. These facts demonstrate that the sea of the Upper Cretaceous period had a far wider extension than that of the Lower Cretaceous. As this sea encroached upon the land which lay to the north of the Wealden area in Lower Cretaceous times, it planed off a considerable thickness of strata, and the surface upon which the Upper Cretaceous rocks now rest in the midland and eastern counties is a plain of marine erosion. Borings at Richmond and at Meux's Brewery in Tottenham Court Road pass from Gault and Lower Greensand into Great Oolite; a boring at Kentish Town passed from Gault into red sandstones which are probably of Palæozoic age, while borings in Essex, Herts, and Suffolk came down upon Palæozoic rocks of Silurian and Devonian age. The following are abstracts of some of these borings:—

	Richmond.	Meux's Brewery.	Kentish Town.	Cheshunt.	Ware.	Culford.
Gravel and Drift .	11	22	—	26	17	6
Eocene . . .	242	136½	324½	76	—	—
Chalk . . .	671	655½	645	680	573	526
Upper Greensand .	16	28	13½	44	40	—
Gault . . .	201½	160	130½	155	166½	73
Lower Greensand? .	10	—	—	—	—	32½
Great Oolite . .	87½	64	—	—	—	19½
Palæozoic rocks .	170	80	188½	29	35	—
	1409	1146	1302	1010	831½	657

Cretaceous rocks underlie the whole of the south-eastern part of England; their main outcrops form a broad tract which runs across the country from Dorsetshire to the west of Norfolk, and, passing below the Wash, traverse the eastern parts of Lincolnshire and Yorkshire. If the south-easterly dip was maintained without interruption, Cretaceous rocks would not be seen in the south-eastern counties; but this dip is interrupted by several large cross-flexures, the axes of which run in an east and west direction, and by these flexures the Lower Cretaceous rocks are brought to the surface over a large area in the south of England, while the Tertiary rocks are thrown off into two broad troughs or basins.

There are four principal anticlinal axes: one running through Dorset and the Isle of Wight; a second passing through the Vale of Wardour; a third traversing the Vale of Warminster, Winchester, and the north of Sussex; a fourth through the Vales of Pewsey and Kingsclere. It is by the union of the third and fourth of these flexures that the Lower Cretaceous rocks have been brought up in the Wealden area of Kent and Sussex, the structure of which is illustrated on pp. 405 and 408.

North of the Thames valley there are no such disturbances; the easterly dip is almost uninterrupted and the great escarpment of the Chalk is continuous through the counties of Oxford, Buckingham, Bedford, Hertford, Cambridge, and Norfolk, till it sinks beneath the waters of the Wash. In Norfolk the strike is nearly due north and south, but this is changed beneath the Wash, and the rocks emerge in Lincolnshire with a strike to N.N.W., crossing the Humber west of Hull, and forming the districts known as the Lincolnshire and Yorkshire Wolds.

In Ireland Upper Cretaceous rocks crop out in many places beneath the Eocene basalt plateau of Antrim and Londonderry, the whole of which they doubtless underlie.

Upper Cretaceous rocks are also found in the west of Scotland, but though the exposures are very interesting in themselves, the areas occupied by them are very small.

As the two great divisions of the system differ much from each other in lithological character, and to some extent in their fossil contents, and as the lower series occupies a much more limited area than the upper, it will be convenient to deal with them separately; but before entering on the stratigraphical details a little space may be devoted to a brief general account of the flora and fauna of the period as a whole.

Life of the Cretaceous Period

Flora.—Comparatively few traces of the vegetation of the period are found in the Cretaceous rocks of Britain except in the Wealden Beds, in which, as in the Jurassic system, the predominating groups are ferns and cycads. A few conifers, horsetails (Equisetaceæ), and a *Chara* also occur, but Dicotyledons are unknown, although a few examples, the earliest of their class, have been found in the Lower Cretaceous rocks of Spain and of North America.

The flora of the Wealden presents a considerable resemblance to that of the Jurassic strata, but as the early Cretaceous continent was only an extension of the Upper Jurassic land, such a resemblance should not cause any surprise.

In the Upper Cretaceous of the Continent Dicotyledons form an important part of the flora, and include a number of genera which have living representatives, *e.g.* *Acer* (maple), *Cinnamomum* (cinnamon), *Ilex* (holly), *Quercus* (oak), *Platanus* (plane), *Hedera* (ivy), *Populus* (poplar), *Myrica* (myrtle), with *Aralia*, *Magnolia*, *Eucalyptus*, and the extinct genus *Credneria*. Cycads are less numerous than before; subsequently they became rare in Europe, and at

the present day are chiefly found in the tropical and sub-tropical parts of Asia, Africa, Australia, and Mexico.

Fauna.—The general aspect of the Cretaceous fauna resembles that of the preceding Jurassic much more than that of the succeeding Eocene. Throughout the Lower Cretaceous series many genera which were abundant in Jurassic times are still common, such as *Cucullæa*, *Trigonia*, *Corbis*, *Gervillia*, *Perna*, *Pecten*, *Lima*, *Pleuromya*, and *Pleurotomaria*. The Ammonoid genera *Olcostephanus* and *Perisphinctes* continue to be abundant, and the *Belemnitidæ* were nearly as common, but many new genera of Cephalopoda appear,

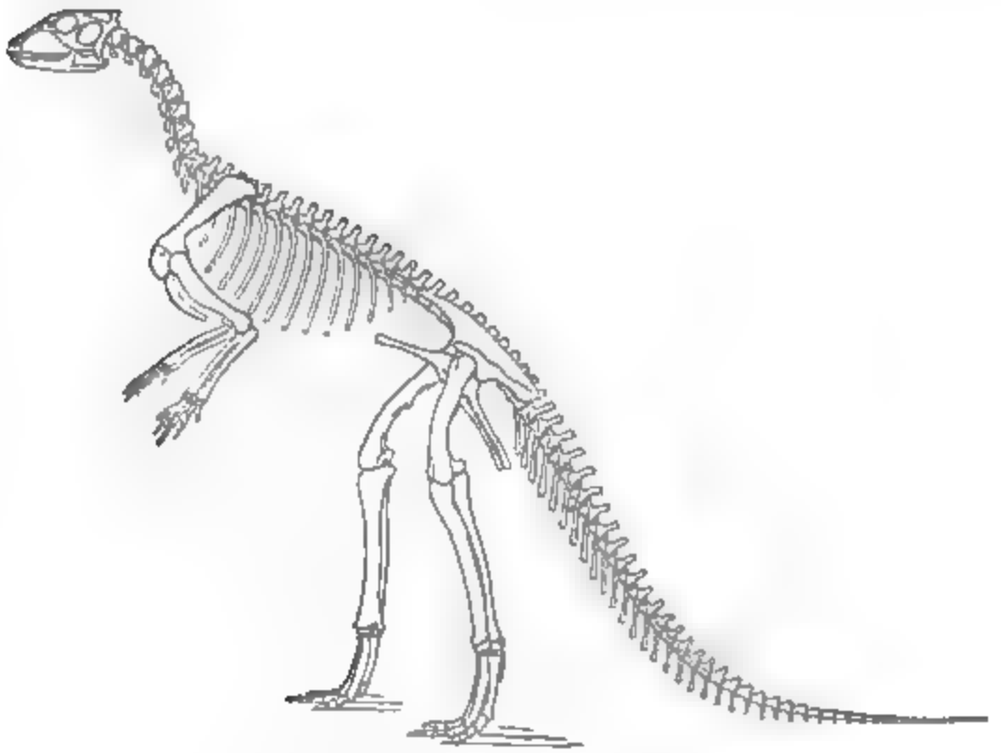

Fig. 128.—RESTORED SKELETON OF HYPSILOPHODON FOXI ($\frac{1}{12}$), (after O. C. Marsh). Over 6 feet long.

some in the lower and some in the upper division of the system. The Echinoid genera *Holectypus*, *Nucleolites*, and *Pygurus* also survive into the Lower Cretaceous, but many new genera make their appearance (see list below).

Passing to vertebrate animals, most of the Cretaceous fish belong to genera which existed in Jurassic times, but *Edaphodon*, *Lamna*, and *Protosphyræna* now appear, while in the Chalk many Teleostean fish resembling modern genera are found, such as *Beryx*, *Corax*, *Osmeroides*, *Enchodus*, *Hypsodon*, and *Portheus*. Among reptiles the marine *Ichthyosaurus* and the Dinosaurian genera *Cetiosaurus* and *Megalosaurus* survive from Jurassic time, but the Plesiosaurs are

represented by *Cimoliosaurus* and *Polyptychodon*. Fresh Dinosaurs make their appearance, *e.g. Iguanodon*, *Hypsilophodon*, *Hylæosaurus*, and *Vectisaurus* in the Lower Cretaceous, with *Acanthopholis*, *Anoplosaurus*, and others in the Upper Cretaceous. In the sea were large lizard-like reptiles (*Coniosaurus*, *Mosasaurus*, and *Dolichosaurus*), and in the air the Pterosauria were represented by species of *Pteranodon* and *Ornithocheirus*.

Remains of birds also occur in the Upper Cretaceous series, but only one genus has been found in Britain, the *Enaliornis* of the Cambridge Greensand. In America remains are more plentiful, and three remarkable genera have been described—*Hesperornis*, *Ichthyornis*, and *Apatornis*. *Hesperornis* was a large bird about six feet in length, and possessing many reptilian characters, so that it forms a link between the Jurassic *Archæopteryx* and more highly-developed birds; its jaws were furnished with teeth planted in a long alveolar groove, its wings rudimentary, and its hind limbs strong, so that it was a wader and lived chiefly on fish. *Ichthyornis* and *Apatornis* were much smaller birds with well-developed wings, but both had reptilian skulls with teeth set in sockets, and their vertebræ were biconcave like those of Fish, Amphibians, and *Ichthyosaurus*.

Mammalia also existed, though remains of them are very rare, and none have been found in England; they consist of teeth of small Prototheria (*Cimolomys* and *Selenacodon*) related to the Jurassic *Plagiaulax*, and some bones of true Marsupials referred to the genera *Didelphops*, *Cimolestes*, and *Telacodon*.

The following are some of the more important marine genera which first appear in the Lower Cretaceous series:—

Porifera. Catagma, Chenendopora, Oculospongia, Ploeoscyphia, Raphidonema, Scyphia, Trematocystia.
Actinozoa. Brachycyathus, Holocystis, Leptophyllia, Trochosmilia.
Echinoderma. Cardiaster, Catopygus, Discoidea, Toxaster (=Echinospatagus), Enallaster, Peltastes, Goniopygus, Salenia.
Crustacea. Hoploparia, Meyeria, Mithracites.
Brachiopoda. Kingena.
Lamellibranchia. Arca, Crassatella, Pectunculus, Monopleura, Requienia, Toucasia, Sphærulites, Thetis, Venus.
Gastropoda. Aporrhais (Ornithopus, Dimorphosoma), Avellana, Eulima, Scalaria, Pleurotoma.
Cephalopoda. Acanthoceras, Desmoceras, Hoplites, Crioceras, Anisoceras, Macroscaphites, Hamulina, Actinocamax.

The following are some of the more important genera which make their appearance in Upper Cretaceous time:—

Porifera. Camerospongia, Cephalites, Cœloptychium, Coscinopora, Doryderma, Guettardia, Hallirhoa, Leptophragma, Nema-

tinion, Plinthosella, Pharetrospongia, Siphonia, Stauronema, Ventriculites, Verruculina.

Actinozoa. Axogaster, Caryophyllia, Cœlosmilia, Cyclocyathus, Micrabacia, Onchotrochus, Parasmilia, Placosmilia, Trochocyathus.

Echinoderma. Caratomus, Cyphosoma, Cottaldia, Galerites (=Echinoconus), Echinocorys, Epiaster, Hemiaster, Holaster, Infulaster, Micraster, Bourgueticrinus, Marsupites.

Crustacea. Callianassa, Etyus, Eucorystes, Necrocarcinus, Palæocorystes, Palæga, Enoploclytia.

Brachiopoda. Magas, Terebrirostra, Trigonosemus.

Lamellibranchia. Chama, Hippurites, Radiolites.

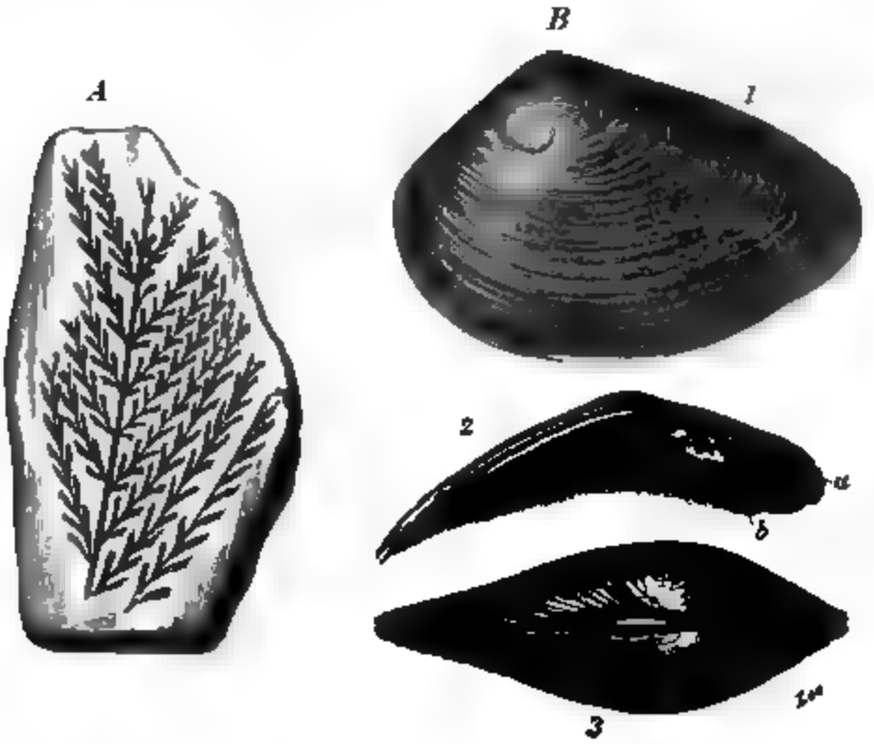

Fig. 129.—FOSSILS OF THE WEALDEN BEDS.

A. Onychiopsis Mantelli. *B.* Unio valdensis.

Gastropoda. Actæonella, Buccinum, Cadulus, Cassidaria, Columbellina, Crepidula, Helix, Fusus, Voluta.

Cephalopoda. Buchiceras, Baculites, Heteroceras, Mammites, Pachydiscus, Placenticeras, Prionocyclus, Schlœnbachia, Scaphites, Turrilites, Belemnitella.

Pisces. Beryx, Corax, Macropoma, Osmeroides, Plethodus Portheus, Ptychodus.

A. LOWER CRETACEOUS SERIES

Characteristic Fossils

The following are some of the species which characterise the several stages of the Lower Cretaceous series. The Wealden

species are of course English, but under the heads of Neocomian and Wealden the species characteristic of these stages in France and Switzerland are given together with some which occur in beds of the same age in Yorkshire; those found in Yorkshire are indicated by an asterisk. The Vectian species are English, though many of them occur also in the Aptian of France.

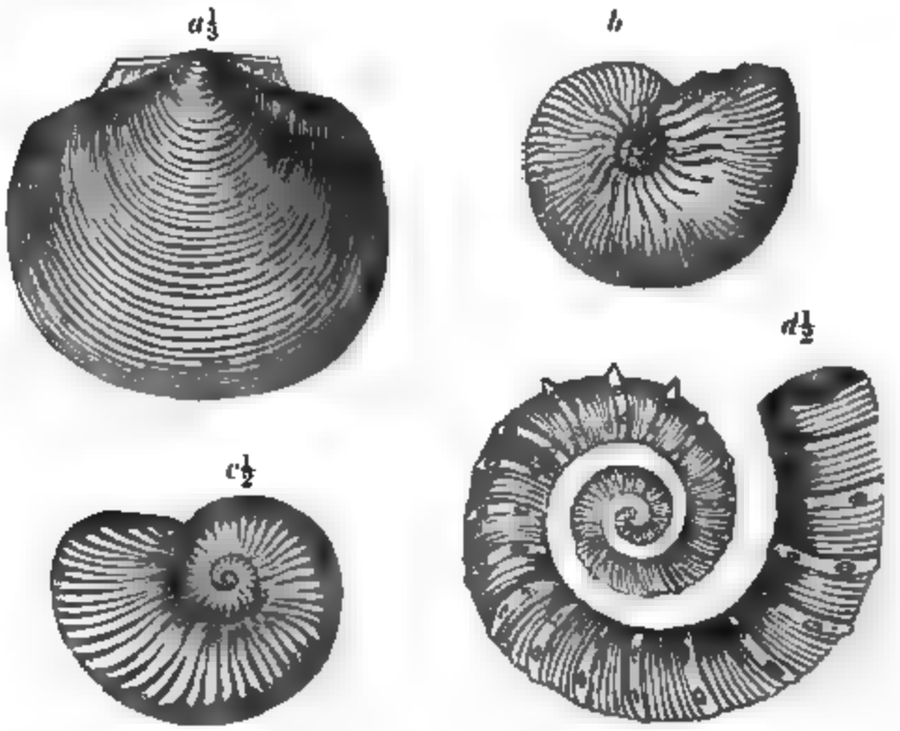

Fig. 130.—GROUP OF FOSSILS FROM THE SPEETON CLAY (Hauterivian and Barremian).

a. Pecten cinctus.
b. Hoplites speetonensis.
c. Hoplites regalis.
d. Crioceras Duvali.

Fossils of the Wealden Beds

Plantæ. Chara Knowltoni, Equisetites Lyelli. *Filices:* Onychiopsis Mantelli, Matonidium Gœpperti, Cladophlebis Albertsi, Sphenopteris Fittoni, Tempskya Schimperi, Weichselia Mantelli. *Cycadaceæ:* Cycadites Rœmeri, Diomites Dunkerianus, Nilssonia Schaumbergensis, Otozamites Klipsteini, Zamites Buchianus, Anomozamites Lyellianus *Coniferæ* · Pinites Dunkeri, Sphenolepidium Kurrianum.

Crustacea. Cypridea valdensis, Cythere Fittoni, Estheria elliptica.

Gastropoda. Viviparus fluviorum, V. carinifera.

Lamellibranchiata. Cyrena media, C. elongata, Unio valdensis, U. compressus, U. aduncus.

Fish. Lepidotus Fittoni, Hybodus dubius.

Reptilia. Iguanodon Mantelli, Hypsilophodon Foxi, Ceteosaurus brevis, Hylæosaurus Oweni, Megalosaurus Bucklandi, Goniopholis crassidens, Chelone Mantelli.

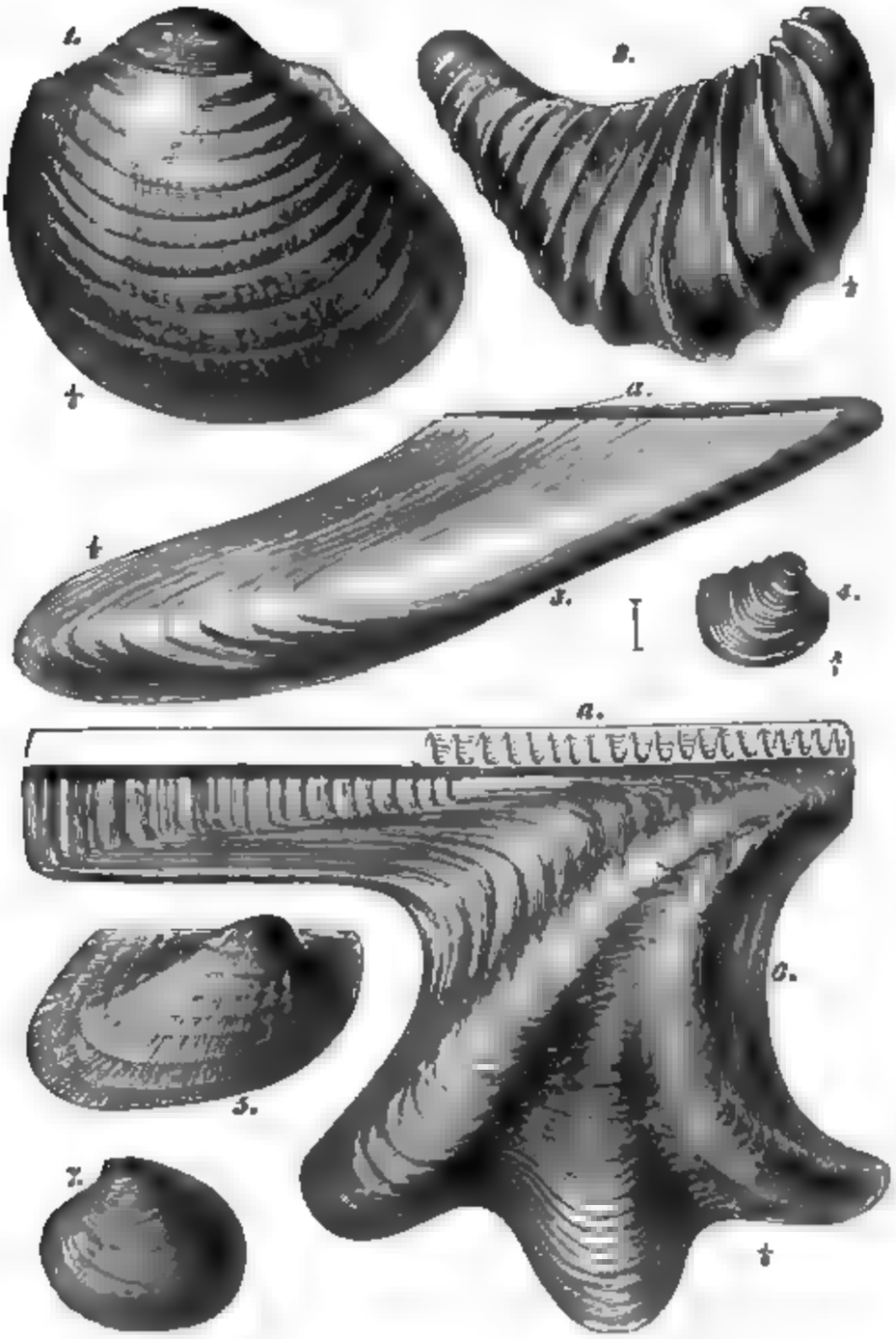

Fig. 131. -GROUP OF NEUTIAN FOSSILS.

1. Corbis corrugata.
2. Trigonia caudata.
3. Gervillia anceps.
4. Venus striato-costata.
5. Arca aptiensis.
6. Perna Mulleti.
7. Venus parva.

Fossils of the Valenginian (and zone of Bel. lateralis)

Echinoderma. Toxaster Campichei, Pygurus rostratus.
Lamellibranchia. *Exogyra sinuata, var. Couloni, *Astarte senecta, *Trigonia ingens.
Gastropoda. Nerinæa Marcouanus, N. Meriani, Strombus Sautieri.
Cephalopoda. Olcostephanus plicomphalus, Hoplites radiatus, H. neocomiensis, *H. regalis, *H. amblygonius, Belemnites dilatatus, *B. lateralis, *B. ruesiensis.

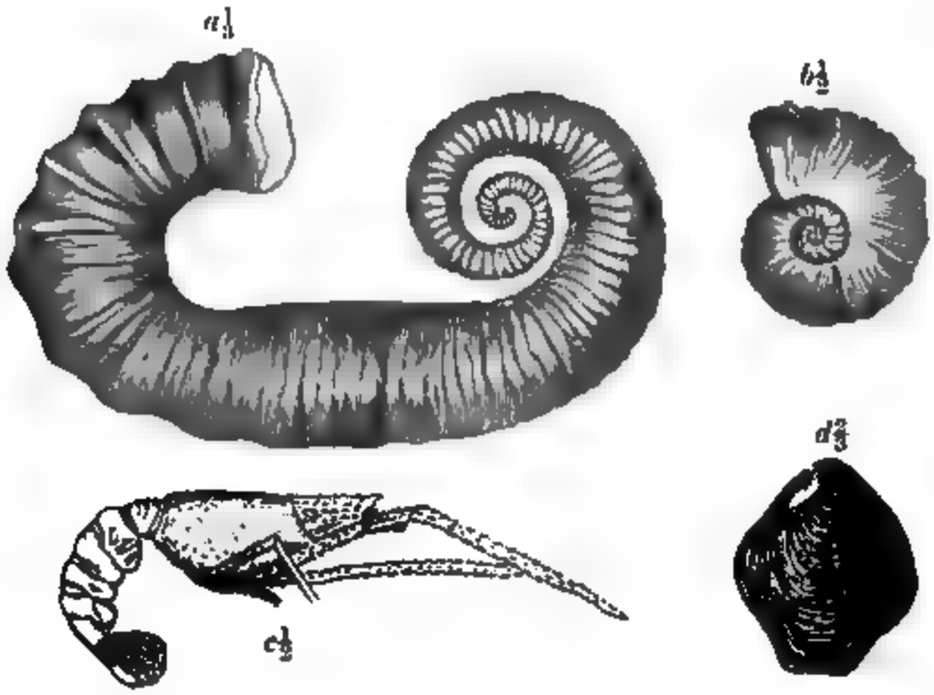

Fig. 132. GROUP OF VECTIAN FOSSILS.

a. Macroscaphites gigas.
b. Hoplites Deshayesi.
c. Meyeria magna (= vectensis).
d. Terebratula sella.

Fossils of the Hauterivian

Echinoderma. *Toxaster complanatus, Holectypus macropygus.
Lamellibranchia. *Exogyra Couloni, Neithea atava, Astarte numismalis.
Cephalopoda. Hoplites radiatus, *H. regalis, H. leopoldinus, *Olcostephanus astieri, *O. rotula, *Crioceras Duvali, Nautilus pseudelegans, Actinocamax jaculum, Bel. dilatatus.

Fossils of the Barremian (and zone of Am. speciosus)

Echinoderma. Heteraster Couloni, H. oblongus, Goniopygus peltatus.
Crustacea. *Meyeria ornata.
Brachiopoda. Rhynchonella lata, *R. sulcata.
Lamellibranchia. *Exogyra sinuata (type), *Pecten cinctus, *Isocardia angulata, Requienia ammonia, Toucasia carinata.
Gastropoda. Pterocera (Harpagodes) pelagi, *Trochus pulcherrimus, *Aporrhais Phillipsi.

Cephalopoda. Acanthoceras Cornuelianum, *Olcostephanus Decheni, *Hoplites regalis, *H. speetonensis, Crioceras Emerici, Ancyloceras Matheroni, *Actinocamax jaculum.

Fossils of the Vectian and Aptian

Echinoderma. Enallaster Fittoni, Peltastes Wrighti.
Crustacea. Meyeria vectensis.
Brachiopoda. Terebratula sella, T. depressa, Terebratella oblonga, T. Fittoni, Waldheimia tamarindus, Rhynchonella latissima.
Lamellibranchia. Exogyra sinuata, Perna Mulleti, Corbis corrugata, Arca aptiensis, Gervillia anceps, Trigonia caudata, T. nodosa, T. ornata, Plicatula placunea, Venus parva, V. striatocostata, Thetis minor.
Gastropoda. Aporrhais robinaldina, A. Fittoni.
Cephalopoda. Hoplites furcatus, H. Deshayesi, Acanthoceras Martini, Macroscaphites gigas, Crioceras Bowerbanki, Nautilus pseudelegans, Actinocamax brunsvicensis.

Stratigraphy

France and Switzerland

The marine facies of the Lower Cretaceous series is most fully developed in the south of Europe, and the nomenclature of its divisions is taken from places in the south of France and in Switzerland. The lower portion of the series is often called the *Neocomian*, from Neuchâtel in Switzerland, where the beds were first studied and described, but this Neocomian has since been subdivided into two parts, the *Valenginian* and the *Hauterivian*, which seem to have the value of separate stages. The next stage is the *Barremian*, from Barrême in the Basses-Alpes, and the highest stage is called the *Aptian*, from Apt in Vaucluse.

The following is the succession to be found near Neuchâtel, where the lower (or Neocomian) stages are typically developed :—

		Feet.
Aptian.	Yellow and blue marls with *Heteraster oblongus*, *Aporrhais robinaldina*, and *Trigonia caudata*, and a red limestone with *Heteraster oblongus* at base . .	60
Barremian.	Light gray and white limestones with *Requienia ammonia* and *Radiolites neocomiensis*, but few other fossils	100
Hauterivian.	Blue and gray marls, rich in fossils, *Belemnites dilatatus*, *Hoplites radiatus*, *Olcostephanus astierianus*, *Toxaster complanatus*, *Exogyra Couloni*, etc. .	about 300
Valenginian.	This comprises red ferruginous limestone with *Bel. dilatatus*, *Pygurus rostratus*, compact white limestone with *Nerinæa* and *Strombus Sautieri*, and oolitic limestones and marls with *Toxaster Campichei* at the base	from 160 to 400

The Barremian is thin near Neuchâtel, but swells out to a thickness of about 1600 feet near Grand Chartreuse in Dauphine, and is from 600 to 2000 feet in Mont Ventoux and the Montagne du Lure near Barrême. There too it is more fossiliferous, yielding *Am.* (*Desmoceras*) *difficile*, *Crioceras Emerici*, *Macroscaphites Yvani*, and *Orbitolites lenticularis*.

The Aptian, again, has a much greater development in the south of France near Apt, Bedoule, and Marseilles, where it is from 300 to 500 feet thick, and is divisible into two zones, the lower containing *Hoplites Deshayesi*, *H. fissicostatus*, and *Ancyloceras Matheronianum*, the upper *Hoplites furcatus*, *Acanthoceras cornuelianum*, and *Actinocamax brunsvicensis*.

The Neocomian sea entered the Parisian basin through a strait which is now the district of Côte d'Or, but it is doubtful whether any Valenginian deposits exist in the Paris basin, for its characteristic fossils have not been found. In Northern France the succession in Haute Marne is the most complete, and is as follows :—

		Feet.
Aptian.	Yellow sands with *Exogyra sinuata* (*O. aquila*) overlying clays with *Plicatula placunea*, *Hoplites Deshayesi* and *Acanthoceras cornuclianum* . .	about 90
Barremian.	Variegated sands and clays, some marine with *Ostrea Leymerii*, some freshwater with *Unio*, *Cyclas*, and *Viviparus*. At the top is a hard red clay with *Heteraster oblongus*, *Gervillia linguloides*, etc. .	about 80
Hauterivian.	Marls and ferruginous sands with the Spatangus limestone, *Hoplites radiatus*, *Nautilus pseudelegans*, *Pteroceras* (*Harpagodes*) *pelagi*, *Toxaster complanatus*, etc.	about 130

It will be noticed that the whole series is thin and sandy, indicating shallow water conditions, and that the Barremian includes freshwater beds which are about 20 feet thick and resemble the Wealden sands of England.

When the fossils of the stages above described are compared with those of the English deposits it will be found that our Vectian or Lower Greensand corresponds with the French Aptian, for the Ammonites of the Atherfield clay are *Hoplites furcatus* and *H. Deshayesi*, the two characteristic Aptian species of Southern France. It follows that our Wealden beds are the freshwater representatives of the French Barremian and Hauterivian.

Hanover

A very different facies occurs in Hanover, where it consists almost entirely of clays, and shows the following succession :—

Aptian.	Clays and marls with *Acanthoceras Martini*, *Actinocamax brunsvicensis*, *Meyeria ornata*, etc.

Barremian. Clays with *Olcostephanus Decheni* and *Crioceras Emerici.*
Hauterivian. Not recognisable.
Valenginian. Clays with *Hoplites radiatus, H. regalis, H. astierianus,* and a pebbly sandstone with *Belemnites lateralis.*

British Equivalents

In England strata of Lower Cretaceous age come to the surface in four districts—(1) the Wealden area, (2) Dorset and the Isle of Wight, (3) a narrow outcrop through Wilts, Berks, Oxford, Bucks, Beds, and Cambridge, (4) Lincolnshire and Yorkshire. The two southern districts may be described together, as they exhibit a similar succession of deposits, and are undoubtedly connected beneath the Chalk of Hampshire (see table on p. 394).

1. *Southern Areas*

The Weald is an oval-shaped area occupying portions of Kent, Surrey, Hants, and Sussex (see map, Fig. 134); on the north-west and south it is bounded by the escarpment of the Chalk, but eastward it opens on to the English Channel between Eastbourne and Folkestone. The district known as the Bas Boulonnais in France is the eastern prolongation and termination of the Wealden area, and the English and French districts are undoubtedly continuous beneath the waves of the English Channel. The structure of this area is generally described as that of an anticlinal ridge, but in reality it more resembles that of an oval dome or inverted boat.

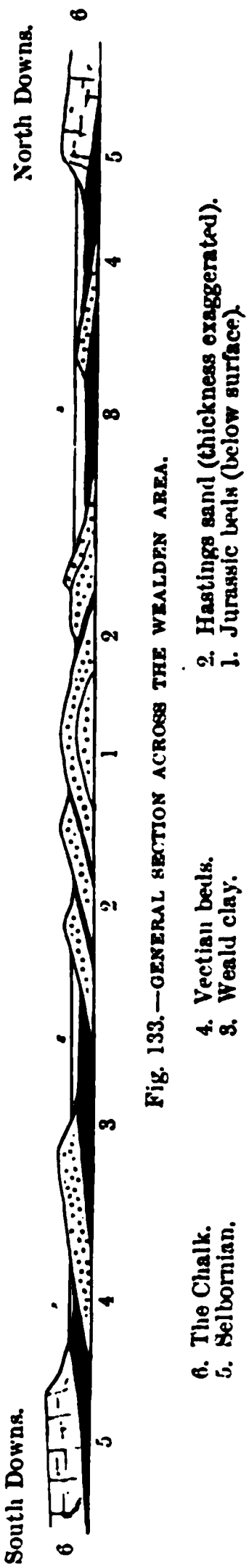

Fig. 133.—GENERAL SECTION ACROSS THE WEALDEN AREA.

2. Hastings sand (thickness exaggerated).
1. Jurassic beds (below surface).
4. Vectian beds.
3. Weald clay.
6. The Chalk.
5. Selbornian.

Fig. 133 is a diagrammatic section across the Weald from north to south, showing its general structure, and regarding only the Cretaceous rocks; Fig. 135 is a more complete and accurate section taken along a line drawn from Beachy Head to Chatham. The absence of the Lower Cretaceous below Chatham has been proved by boring there, which entered the Oxford clay directly below the

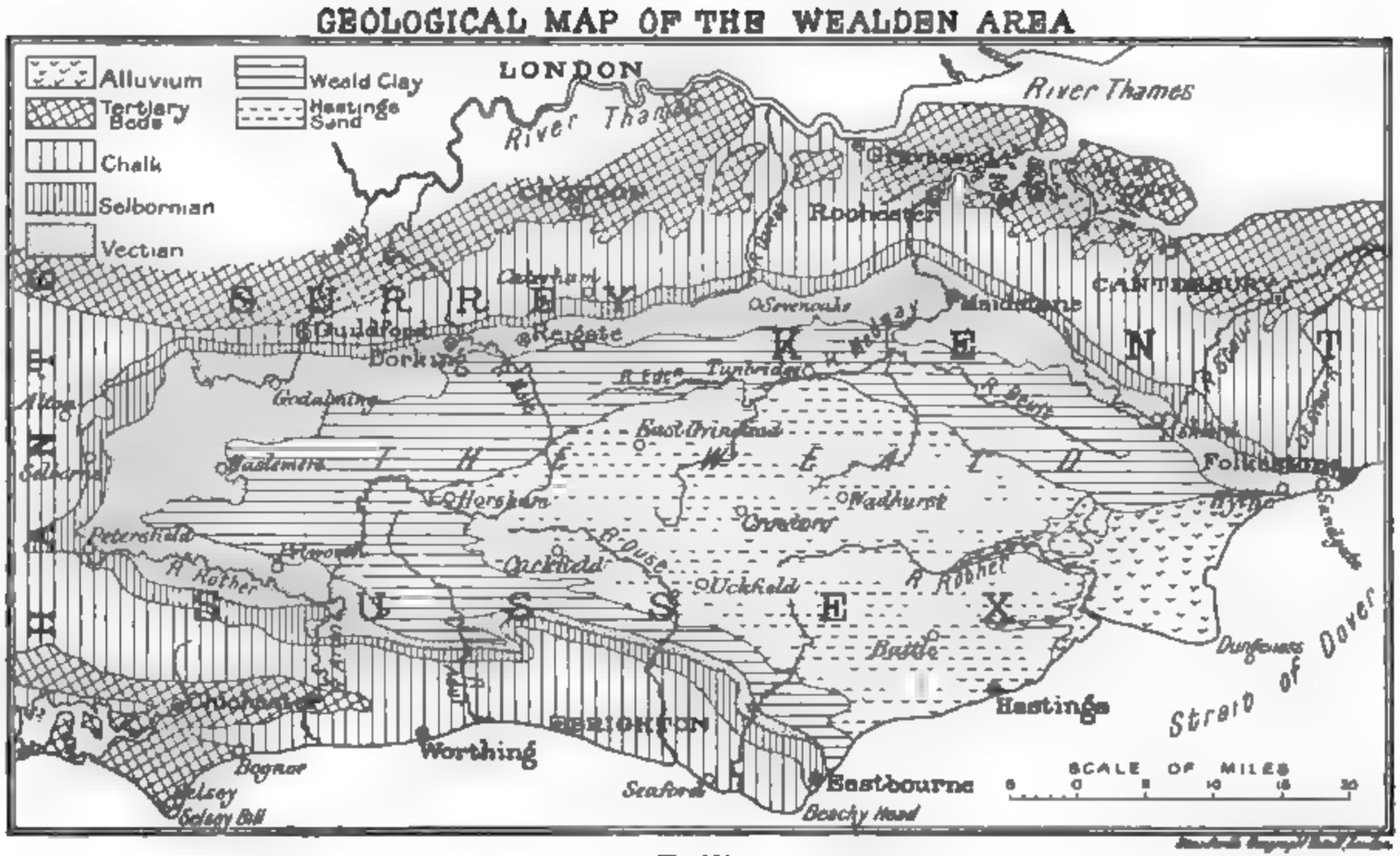
GEOLOGICAL MAP OF THE WEALDEN AREA
Alluvium
Tertiary Beds
Chalk
Selbornian
Vectian
Weald Clay
Hastings Sand
LONDON
River Thames
River Thames
SURREY
KENT
SUSSEX
Guildford
Dorking
Reigate
Godalming
Tunbridge
Sevenoaks
Maidstone
Canterbury
Folkestone
Hythe
Sandgate
Dungeness
Strait of Dover
Hastings
Battle
Uckfield
Crowborough
Wadhurst
Haslemere
Petersfield
Midhurst
Arundel
Worthing
Bognor
Selsey
Selsey Bill
Seaford
Eastbourne
Beachy Head
SCALE OF MILES

Fig. 134.

Vectian sands, and this part of the section is reduced from that drawn by Mr. W. Whitaker.

In the Isle of Wight, and again in South Dorset, from Swanage to Ridgeway near Weymouth, the Lower Cretaceous series is brought to the surface by a sharp anticlinal curvature.

The following is a tabular view of the subdivisions which have been made in the series as developed in these two districts :—

	Weald.	Isle of Wight.	Thickness. Feet.
Vectian [a]	Folkestone beds, Sandgate beds	Carstone, Sandrock series	160 to 200
	Hythe beds	Ferruginous sands	280 to 520
	Atherfield clay	Atherfield clay	60 to 130
Wealden	Weald clay	Weald clay	up to 900
	Hastings sands	Not seen	up to 1000

Wealden Beds.—In the Wealden area the Wealden beds are divisible as follows, all the divisions being thickest in the western and thinnest in the eastern part of the area :— [1]

		Feet.
Weald clay		900 to 350
Hastings sands	Tunbridge sand	380 to 150
	Wadhurst clay	160 to 100
	Ashdown sand	500 to 400
		1940 to 1000

The Ashdown sand consists of soft buff or white sand and sandstone, which are 400 feet thick in Ashdown Forest, and form the high ground of Crowborough Beacon (800 feet high). Near Hastings and Fairlight the lower part of this sand is replaced by clays with interbedded sandstones (350 feet thick), which are surmounted by 150 feet of sand and sandstone. A few plant-remains are the only fossils.

The Wadhurst clay, though never more than 160 feet thick, is palæontologically important, as it is rich in fossils, and contains a bone bed near Battle, from which many reptilian bones and teeth have been obtained. It consists of clays and shales, with

[a] It is high time that the names Upper and Lower Greensand were abandoned, for they were proposed by Webster at a time (1824) when the beds between the Chalk and the Wealden were regarded as the "Greensand Formation." Thus they only perpetuate erroneous views of classification, and are, moreover, cumbrous and misleading, for the "Lower Greensand" is more often yellow or brown than green. Hence it is desirable that the name *Vectian* (altered from the *Vectine* of Fitton) should be adopted instead of Lower Greensand, while the "Upper Greensand" falls into the group of beds for which the name *Selbornian* has recently been proposed.

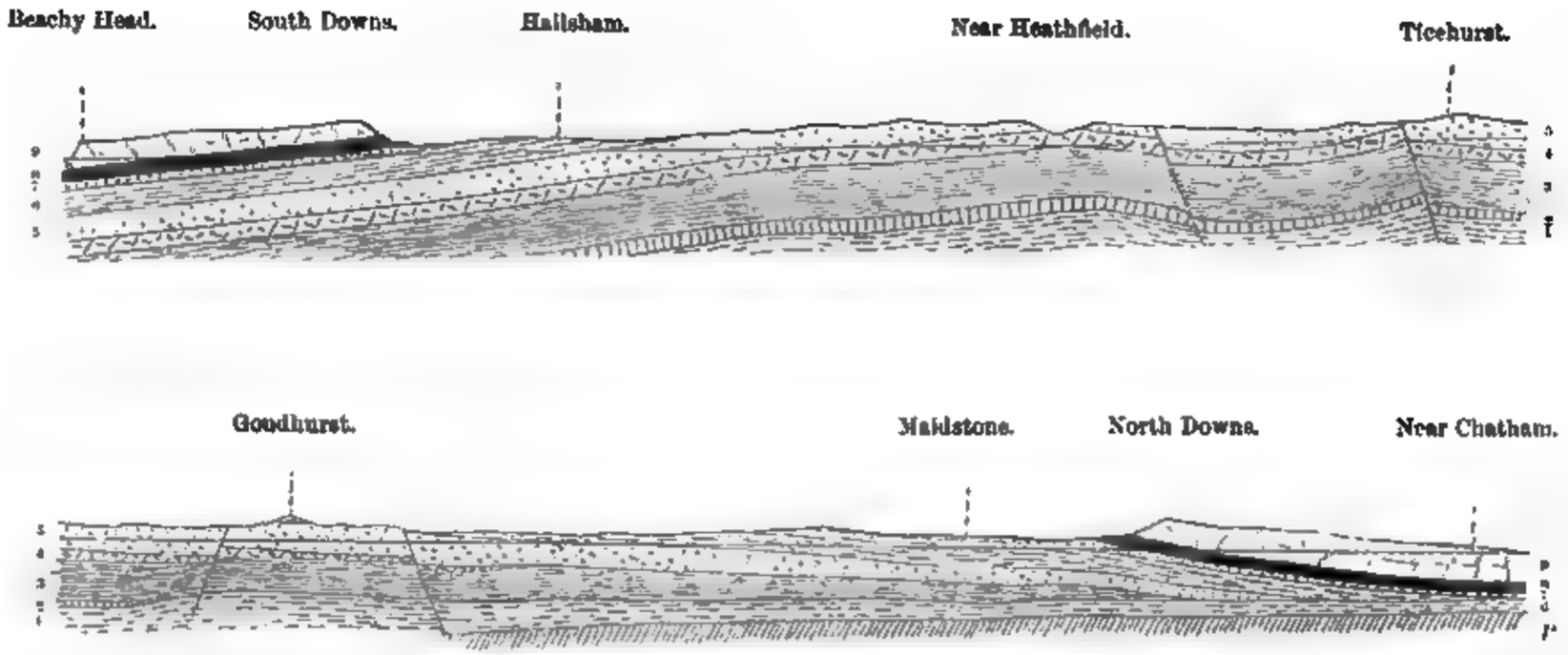

Fig. 185.—SECTION ACROSS THE WEALD OF KENT AND SUSSEX VIEWED FROM THE EAST. Distance about 50 miles.
(Details of northern part after W. Whitaker.)

9. Chalk (Lower, Middle, and Upper).
8. Selbornian (Gault and Upper Greensand).
7. Vectian (or Lower Greensand).
6. Weald clay.
5. Hastings sands.
4. Purbeck beds.
3. Portlandian and Kimeridgian.
2. Corallian.
1. Oxfordian.
P. Palæozoic rocks.

bands of irregular layers of hard calcareous sandstone (Tilgate stone). The fossils are *Viviparus fluviorum*, *Cyrena media*, *Lepidotus Mantelli*, *Hybodus basanus*, *Goniopholis crassidens*, *Iguanodon*, and *Megalosaurus*.

The Tunbridge Wells sands are lithologically similar to the Ashdown sands. Near Hastings their thickness is only 150 feet, but it increases steadily toward the west, a set of mottled clays and shales coming in at the same time in the middle of the sands, and becoming of sufficient importance to deserve a separate name, the Grinstead Clay. In the upper sands of the Cuckfield district, which is often called the Tilgate Forest, there are large concretionary masses of calcareous grit or sandstone, such as were termed Tilgate stone by Dr. Mantell. It was in these masses that the remains of *Iguanodon* and *Hylæosaurus* were first discovered by Dr. Mantell, and the specimens which he figured and described are now in the South Kensington Museum.

The upper member of the Wealden group consists mainly of brown and blue clays, with layers of shelly limestone and occasional beds of sand and calcareous sandstone. The limestones are known as Sussex marbles, and are composed almost entirely of *Viviparus* shells, those in the lower part of the clay consisting chiefly of *V. sussexensis*, while the most constant band (the Petworth and Bithersden marbles) consists of *V. fluviorum*. The minute freshwater Crustaceans (*Cypridea*) are also very abundant in some places, the surfaces of the more shaly beds being crowded with them. Shells of *Unio* and *Cyrena* also occur. At Haslemere the highest beds, just below the Atherfield Clay, contain *Corbula* and *Mytilus*, as well as *Cyrena* and *Melanopsis*, indicating the change from freshwater to marine conditions. The Weald clay near Horsham was estimated by Topley to be from 900 to 1000 feet thick, but it diminishes eastward to about 600 feet at Tonbridge, and near Hythe it may not be more than 350 feet, and in the boring recently completed at Dover it was entirely absent.

In the Isle of Wight[2] Wealden beds are exposed both on the eastern and western sides (see map, Fig. 134). The equivalent of the Hastings sands is not visible; the lowest beds seen are those at Brook Point in Compton Bay, and consist of a pale sandstone overlain by red and green marls in which the broken trunks of pine-trees are so numerous that it would seem as if a raft of waterlogged trees had here sunk to the bottom, a frequent occurrence in the deltas of large rivers like the Mississippi; the spot is known to local geologists as the "pine-raft." The higher beds, consisting of variegated marls or clays with thin beds of sand-

stone, can be seen by walking along the coast to the southward; they have yielded bones and footprints of *Iguanodon*, *Hypsilophodon*, and other reptiles, with *Unio valdensis*, but other fossils are rare in this lower division, which has a thickness of about 700 feet.

The higher beds are well exposed between Cowleaze Chine and Atherfield Point; they consist almost entirely of gray shales with some beds of sandstone, ironstone, and limestone. These beds are much more fossiliferous, containing species of *Meta*, *Cypris*, *Cypridea*, and *Candona*, with *Cyrena*, *Viviparus*, and *Vicarya* (a subgenus of *Potamides*). Small oysters also occur near the top. This series of beds is about 200 feet thick, and is directly overlain by the "Perna bed" mentioned below.

The whole of the Wealden comes to the surface near Swanage in Dorset, and extends thence along a broad valley to Worbarrow Bay on the other side of the Isle of Purbeck. At Swanage the estimated thickness of the formation is about 2300 feet,[3] but the junction with the Purbeck is not exposed. The lower beds consist of variously coloured sands and clays—red, yellow, gray, and white. The succeeding beds are red, purple, and white clays with beds of sand, and they contain layers of lignite and, in one place, the broken trunks of trees. At the top are shales like those of the Isle of Wight, but only 34 feet thick.

The greater part of the Wealden is exposed in the cliffs of Worbarrow Bay, but here its total thickness is reduced to about 1200 feet, and it consists entirely of alternating sands and clays with much lignite. The formation continues to diminish westward, and where last seen at Ridgway the thickness exposed is only 350 feet, but this may not be the full amount.

Wealden clays are found over a small space in the Vale of Wardour, but cannot there be much more than 100 feet thick. Probably they do not extend much farther northward, but their termination is concealed by the overlap of the Upper Cretaceous rocks.

Vectian.—In the Wealden district the lithological characters of the beds composing this stage are very variable, but four subdivisions are generally recognised (see p. 407 and Figs. 136, 137). Along the north side of the Weald the thickness of the Vectian varies from about 500 feet in Surrey to 240 near Sandgate, and about the same in the boring at Dover.

The Atherfield Beds are exposed on the Kentish coast between Sandgate and Hythe, and are traceable thence all round the area occupied by the Weald clay, except between Lewes and Eastbourne. In Surrey they are traversed by the railway cuttings at Sevenoaks and Red Hill, *Panopæa plicata*, *Exogyra sinuata*, *Perna Mulleti*, and

Trigonia dædalea being common fossils ; along this line their thickness varies from 30 to 50 feet. At Haselmere it is 60 feet, and their junction with the Wealden was observed by Mr. Salter, who says "the change from dark grayish blue clay (Wealden) to the purely marine deposit of brown clay was marked no less by the fossils than by the change in the colour of the bed." Within a few inches of the Wealden clay he found *Pleuromya plicata* abundantly embedded in the vertical position which such molluscs occupy when alive. This shows how quiet and gentle was the change from estuarine to marine conditions of deposit.

Hythe Beds.—In Kent, between Hythe and Sevenoaks, these beds consist of greenish yellow sand, often marly or argillaceous, and hard bluish gray calcareous sandstone, the soft beds being locally known as hassock, and the hard beds as rag ; the latter are quarried for lime-burning and building purposes, and when exported are known as Kentish rag. The beds of rag and hassock alternate in regular layers, and these alternations are sometimes so frequent that no fewer than 28 such layers, or courses, have been counted in a vertical depth of 30 feet. From Hythe to Maidstone the thickness of these beds is only from 70 to 80 feet, but they increase rapidly westward, and are 160 feet at Sevenoaks, and still thicker in Surrey.

This increase of thickness is mainly due to the incoming of an upper set of sands with frequent layers of brown chert. These upper beds attain their maximum thickness about Reigate, Dorking, and Leith Hill, where the lower group of soft ferruginous sand is from 100 to 130 feet, and the cherty beds are also in places over 100 feet thick. The Hythe Beds maintain this facies all round the western end of the Wealden area, but thin rapidly eastward again as they are traced along the southern border, disappearing entirely near Lewes.

The chief fossils of the Hythe Beds are *Terebratula sella*, *Exogyra sinuata*, *Trigonia spinosa*, *Tr. ornata*, *Actinocamax brunsvicensis*, *Nautilus pseudelegans*, *Ancyloceras Bowerbanki*, *Macroscaphites gigas*, *Ammonites Deshayesi*, *Am. Hambrovi*, and *Crassatella robinaldina*.

Sandgate Beds.—These are a variable set of beds, but are generally more or less argillaceous. At and near Sandgate they consist of dark green clayey sand full of glauconite grains, and about 70 feet thick. Fossils are not numerous, but at the base, resting on the Hythe Beds, there is frequently a layer of pebbles and phosphate nodules, with brachiopods and other fossils in the state of casts.

In Surrey this division is represented by the Nutfield and

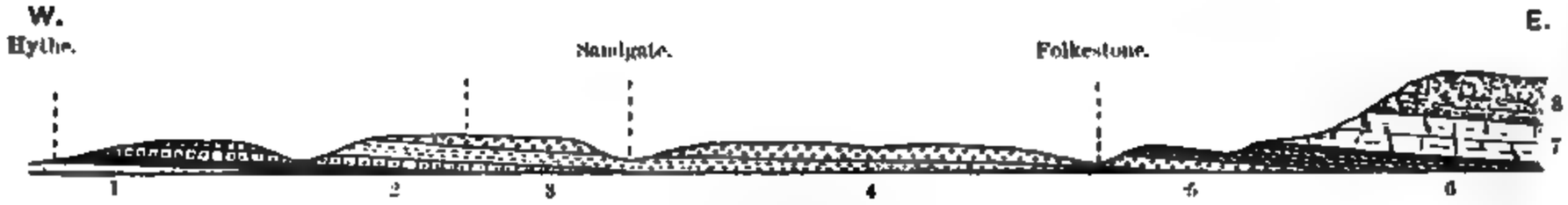

Fig. 136.—SECTION THROUGH HYTHE AND FOLKESTONE. Distance about 6 miles.

8. Middle Chalk.
7. Lower Chalk.
6. Gault (Selbornian).
5. Folkestone Beds.
4. Sandgate Beds.
3. Hythe Beds.
2. Atherfield Clay.
1. Weald Clay.

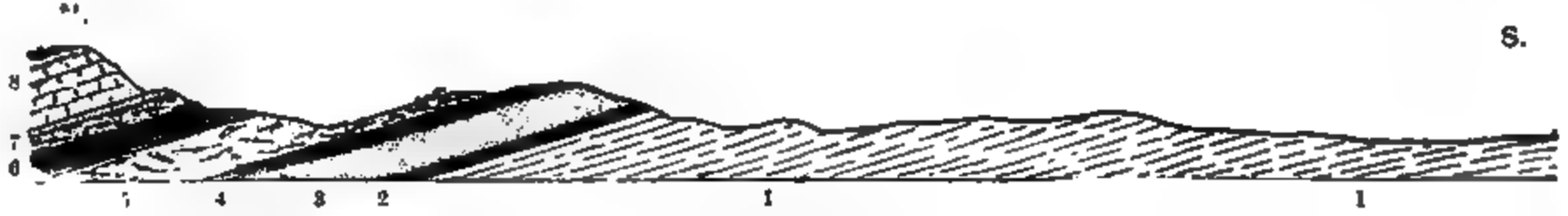

Fig. 137.—SECTION THROUGH THE CRETACEOUS BEDS OF SURREY NEAR DORKING. Distance about 8 miles.

8. Lower and Middle Chalk.
7. Upper Greensand.
6. Gault.
5. Folkestone Beds.
4. Sandgate Beds.
3. Hythe Beds.
2. Atherfield Clay.
1. Wealden Beds.

Bargate beds, which at Nutfield present the following succession in descending order : [4]—

	Feet.
Soft sandstone and calcareous greensand . .	25
Fuller's earth, a fine silty clay	20
Sand with chert beds	8
Sands with pebbles	up to 16

Between Reigate and Godalming the Bargate beds consist of sands and hard calcareous grits (Bargate stone), with some thin layers of fuller's earth and coarse pebbly beds at the base, containing phosphate nodules and many fossils ; the whole thickness is about 50 feet. *Avicula pectinata* is a characteristic fossil of the Bargate stone ; *Terebratula oblonga*, *T. depressa*, *Waldheimia tamarindus*, *Terebratella Fittoni*, *T. trifida*, and *T. Menardi* are some of the fossils occurring in the pebble beds, and with them are many fossils derived from the Oxford Clay, which must at that time have formed part of the shore-line north of Godalming.

In Hants and West Sussex the Sandgate beds reappear in a more normal form, consisting of shaly clay at the top, with sand and sandy clay below.

Folkestone Beds.—At Folkestone these consist of light green and gray sand with beds of hard stone, partly siliceous and partly calcareous in composition, which have been described by Dr. G. J. Hinde as veritable sponge-banks, the sponges being of the Hexactinellid order, and their fine needle-like spicules are clearly visible on weathered portions of the rock. The total thickness is about 80 feet. Fossils are not abundant in these beds, but they have yielded *Avicula pectinata*, *Exogyra sinuata*, *Pecten* (*Neithea*) *atava*, *Neithea Morrisi*, *Ostrea frons*, and *Waldheimia pseudojurensis*.

For a few miles inland the composition of the Folkestone beds is much the same, but west of Saltwood they begin to change their character, the cherty sponge-beds disappear, and the sands are chiefly white, yellow, and brown, current-bedded, and including irregular layers of ironstone. This facies they preserve with little change all round the Wealden area, and consequently the name of Folkestone beds is not a very happy one. In Sussex they include thin bands of hard, ferruginous grit, which is locally known as *carstone*. In Surrey and Hants they are from 130 to 160 feet thick, but like all other members of the Vectian, they thin eastward through Sussex, till near Eastbourne the whole stage appears to be absent, and the Gault rests directly on the Weald clay.

In the Isle of Wight the Vectian also varies much in thickness, being over 800 feet at Atherfield, and only half this thickness in

Compton Bay. The following subdivisions are recognised by Mr. Strahan :—

	Feet.
4. Carstone	6 to 72
3. Sand-group rock	81 to 184
2. Ferruginous sands	251 to 520
1. Atherfield clay	60 to 85

The *Atherfield Clay* has at its base two beds which are together known as "Perna bed," because *Perna Mulleti* is common in them and does not occur above. The lower bed consists of sandy clay, with a thin basal seam of coarse grit containing rolled fragments of fossils and many broken bones and teeth of fish ; this clay is 2½ feet thick, and is succeeded by a bed of brown calcareous sandstone also 2½ feet. Both layers contain many fossils. The rest of the subdivision consists of pale blue clay with many flat calcareous concretions, and the upper part is known as the "lobster bed," from the occurrence of *Meyeria magna*. Other fossils found in these beds are *Nautilus radiatus*, *Ammonites furcatus*, *Am. leopoldinus*, *Am. Deshayesi*, *Corbis corrugata*, *Pinna robinaldina*, and *Enallaster Fittoni*.

The *Ferruginous Sands* consist of alternating beds of sand and clay, the sands of gray, green, or yellow tints, and the clays brown or blue. The lowest beds are known as "the crackers," and contain *Ammonites Hambrovii*, *Gervillia anceps*, *Trigonia caudata*, *Pleuromya plicata*, etc. The overlying beds contain *Terebratula sella* in great profusion, with *Ammonites Martini*, *Macroscaphites gigas*, *M. Hillsi*, and *Crioceras Bowerbanki*. These beds correspond to the Hythe beds. The highest part of the "ferruginous sands," however, appears to be the equivalent of the Sandgate beds ; this consists of two belts, each about 20 feet thick, the lower of sand with ferruginous concretions, the upper a bed of clay without fossils. The concretions yield *Rhynchonella sulcata*, *Avicula pectinata*, *Thetis Sowerbyi*, *Cyprina angulata*, and *Trigonia vectiana*.

The *Sand-rock Group* appears to be the representative of the Folkestone Beds. It consists mainly of coherent sands with bands of laminated clay, but contains no fossils. The *Carstone* is a coarse ferruginous grit which varies greatly in thickness, being 72 feet thick at Redcliff, north of Sandown, but only from 6 to 12 feet on the western side of the island. It contains rolled pebbles and phosphatic nodules, and is considered by Mr. Strahan to be more closely connected with the Gault than with the Vectian. The fossils found in it comprise *Ammonites Bendanti*, *Plicatula carteroniana*, and *Lima parallela*.

When followed across to Dorset the Vectian is found to be

much reduced in thickness, being only 200 feet at Punfield Cove, near Swanage, 136 at Worbarrow Bay, and 66 in Mupe Bay, beyond which it is not seen. At Punfield the Atherfield Clay is 50 feet thick, and the upper part contains some remarkable fossils, especially species of *Vicarya*, *Natica*, *Actæon*, *Cerithium*, and *Pleurotoma*, which are common in the Rhodanian of Spain, but have not been found elsewhere in England.

2. *Midland District*

Under this head will be noticed the deposits which are found along the inland outcrop from Wiltshire into Cambridgeshire. The Wealden clays are only seen in one locality, the Vale of Wardour, where they are succeeded by a small thickness of Vectian sand. North of this only the upper part of the Vectian is represented by a group of sands, ironstones, and pebble beds, which rest unconformably upon the Upper Jurassic rocks, being found successively on Corallian, Kimeridgian, Portland, and Purbeck Beds. They vary greatly in thickness and in lithological characters, and are sometimes overlapped by the Gault, so that their outcrop is concealed for a space by that clay. Their outcrop is thus broken up into a series of short tracts and patches.

Near Faringdon (see Fig. 138) the Vectian consists for the most part of soft yellow and brown sands, with some layers of sandstone and thin bands of ironstone, but at the base there are irregular beds of pebbly, fossiliferous gravel, compacted in places into a conglomerate. The pebbles are chiefly of quartz and porcellanous slate (lydianite). Among the fossils sponges, brachiopods, and echinoids are conspicuous, the following being some of these :—

Pecten aptiensis.
,, (Neithea) ornithopus.
Terebratula tornacensis.
,, depressa.
Waldheimia tamarindus.
Terebratella Menardi.
,, Fittoni.
Rhynchonella latissima.
Peltastes Wrighti.
Cidaris faringdonensis.
Raphidonema porcatum.
,, faringdonensis.
Trematocystia anastomosans.
Peronidella ramosa.

The summit of Shotover Hill, south-east of Oxford, consists of ferruginous sands with bands of ochre and cream-coloured loam, which contain remains of freshwater shells, *Unio*, *Cyrena*, and *Viviparus*. Similar beds occur at Wheatley, Brill, Crendon, and Thame, where they include beds of gray and lilac clay. At Crendon, *Pecten aptiensis* has been found in a layer of calcareous concretions which overlies the clays, and marine fossils have also been found at Stone near Aylesbury. Hence there can be little doubt that the

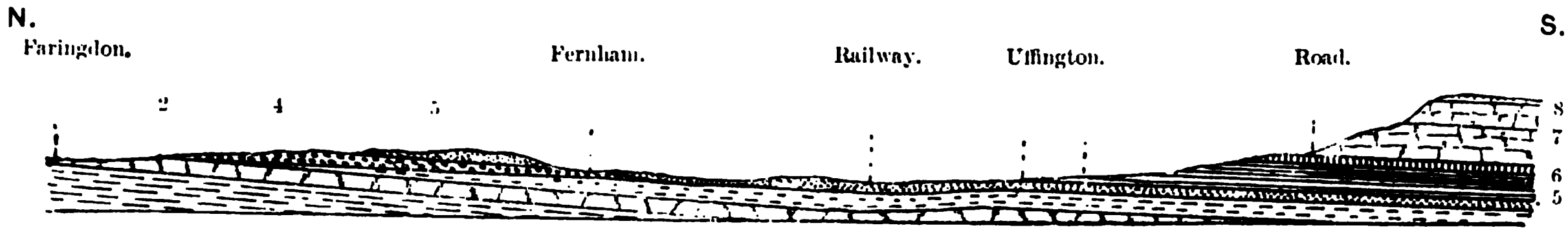

Fig. 138.—SECTION FROM FARINGDON TO THE ESCARPMENT OF THE CHALK NEAR WHITE HORSE HILL (BERKSHIRE). Distance about 6 miles.

8. Middle Chalk.
7. Lower Chalk.
6. Selbornian.
5. Fine sands } Vectian.
4. Conglomerate }
3. Kimeridge Clay.
2. Corallian Beds.
1. Oxford Clay.

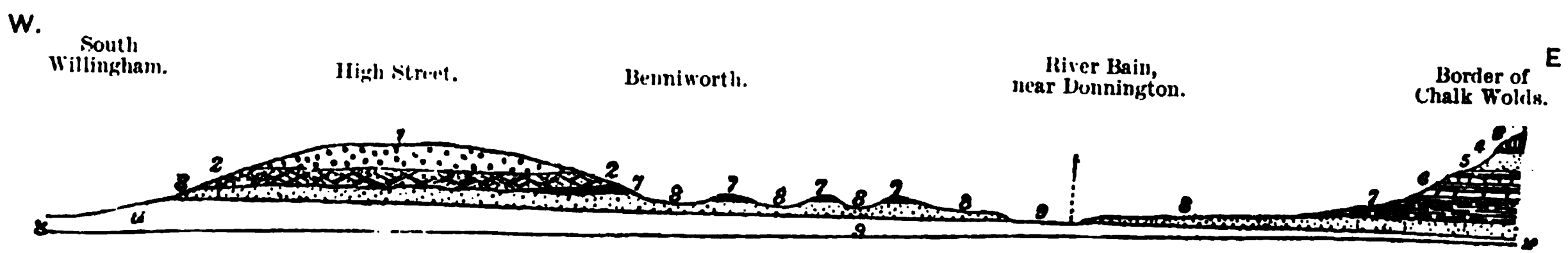

Fig. 139.—SECTION THROUGH THE LOWER CRETACEOUS SERIES NEAR DONNINGTON (LINCOLNSHIRE). Distance about 8 miles.
By Mr. A. Strahan in *Proc. Geol. Assoc.*

1. Boulder-clay.
2. Glacial sands and gravel.
3. Lower Chalk.
4. Red Chalk (Selbornian).
5. Carstone.
6. Tealby Limestone.
7. Tealby Clay.
8. Spilsby Sandstone.
9. Kimeridge Clay.

Shotover Beds, which rest in some places on Portland, in others on the Purbeck Beds, are freshwater deposits of Aptian age. Their thickness is variable with a maximum of about 50 feet.[5]

Yellow and white sands emerge from beneath the Gault near Leighton Buzzard, and form a range of hills by Woburn and Ampthill as far as the neighbourhood of Shefford. Near their base are beds of phosphatic nodules, which were worked near Brickhill, and include casts of fossils derived from the underlying Jurassic clays, together with well-preserved contemporaneous fossils. Among the latter are *Terebratula sella*, *T. depressa*, *T. microtrema*, *T. moutoniana*, and others, *Terebratella Menardi*, *T. Fittoni*, *Waldheimia celtica*, *W. tamarindus*, and others, *Peltastes Wrighti*, and many of the Faringdon sponges.[6]

The sands above are dug for glass-making purposes, and are believed to be about 200 feet thick near Woburn; they also contain a band of fuller's earth, which has been worked for more than a century.

These Woburn Sands, passing beneath the valley of the Ivel, become conspicuous again near Sandy and Potton, with the same nodule beds near the base, in which derived reptilian bones are very abundant; thence the sands run through Cambridgeshire to the Fens south of Ely, near Streatham and Upware.

At Upware in the Fens of Cambridgeshire are sands and silts with two nodule beds similar to those of Brickhill and Potton, but containing a still larger number and variety of fossils.[7] The beds are banked against the Corallian limestones, are less than 12 feet thick, and are overlain by the Gault, so that they seem on the point of thinning out. Besides the species previously quoted from Brickhill, there are here a number of gastropod and bivalve Mollusca which do not occur in Bucks. Specimens of *Acanthoceras cornuelianum* and *Ancyloceras Hillsi* have also been found with *Belemnites* like *B. jaculum*.

3. *Northern District*

This includes the Lower Cretaceous tracts in the counties of Norfolk, Lincoln, and York. Each of these exhibits a somewhat different facies, the deposits in Norfolk being mainly sands, while those in Yorkshire are clays, and those in Lincolnshire are sands, clays, and limestones. In the two latter counties we have a more complete succession of marine deposits of Lower Cretaceous age than is found in any other part of England, and our detailed knowledge of them is mainly due to the labours of Professor J. W. Judd and Mr. G. W. Lamplugh.[8] Unfortunately the Norfolk

outcrop is separated from that in Lincolnshire by the breadth of the Wash, and the beds in South Yorkshire are entirely concealed by the overlap of the Upper Cretaceous, so that correla-

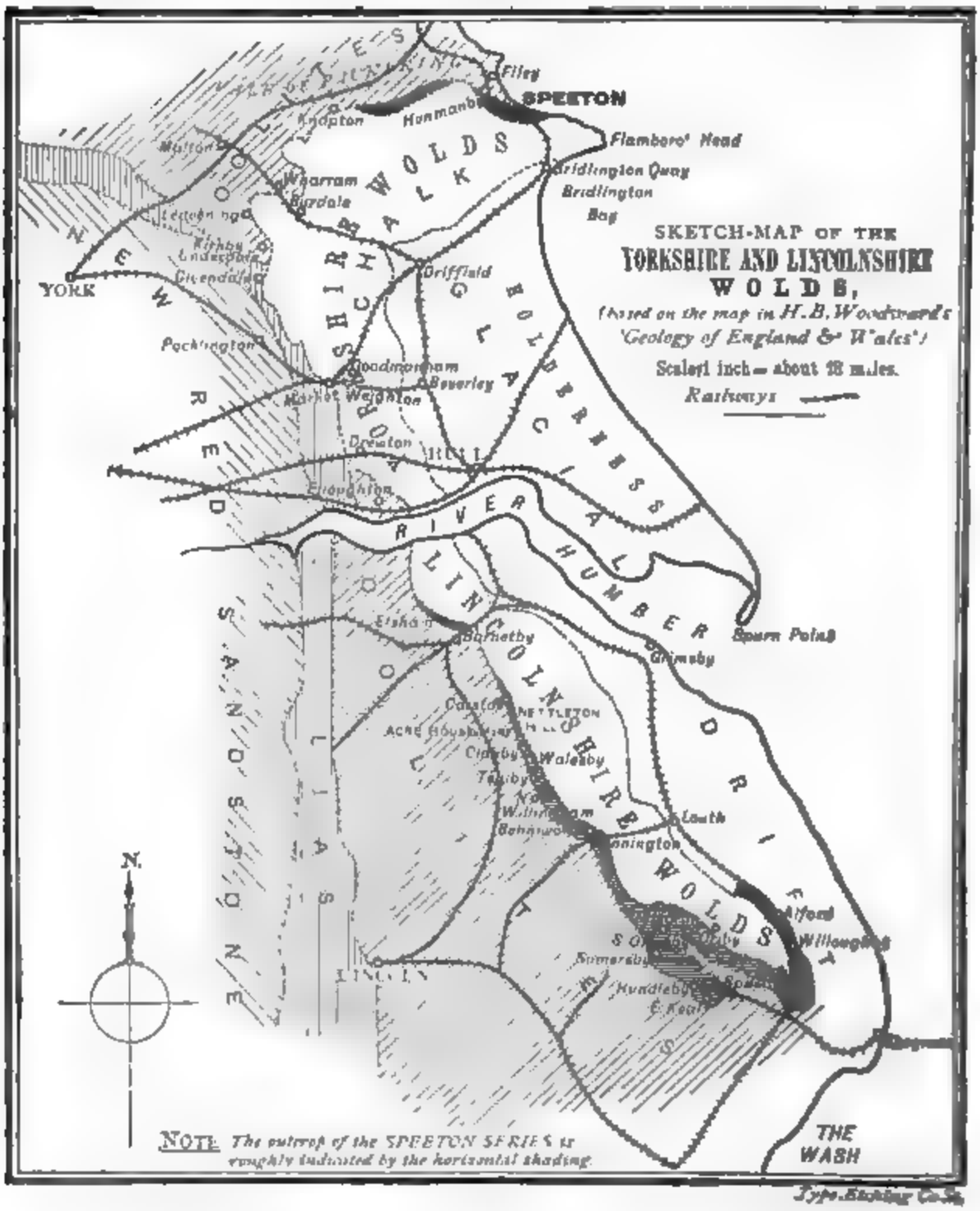

Fig. 140.—MAP OF THE CRETACEOUS AREAS IN LINCOLNSHIRE AND YORKSHIRE.
By G. W. Lamplugh (from *Quart. Journ. Geol. Soc.* vol. lii. p. 187).

tion is rendered difficult and is dependent on the discovery of fossils. The probable correlation is shown in the following table :—

Yorkshire.	Lincolnshire.	Norfolk.
Clays with *Actinocamax brunsvicensis*	Carstone Tealby limestone and Roach ironstone	Carstone Snettisham clay
Clays with *Act. jaculum*	Tealby clay	Sandringham sands
Clays with *Belemnites lateralis*	Claxby ironstone Spilsby sandstone	(Absent)

It will be convenient to take Yorkshire first, and in that county the only good exposure is on the coast near Speeton Gap, and hence the whole series, which has a total thickness of about 330 feet, is sometimes termed the Speeton Clay.

The base of this clay is a layer of black phosphatic nodules embedded in stiff clay. The fossils are badly preserved, but among them Professor Pavlow identifies *Belemnites absolutus* with Ammonites resembling *Olcostephanus Panderi* and *Olc. scythicus*, species characteristic of beds in Russia which are regarded as Portlandian. It is a question, however, whether these fossils are contemporaneous or derived. This bed is succeeded by clays which contain *Belemnites lateralis*, *Olcostephanus subditus*, *Olc. Lamplughi*, *Hoplites amblygonus*, with *Exogyra Couloni* and *Astarte senecta*. These clays are considered to be of Purbeck age by Professor Pavlow, but as they contain some Cretaceous species it seems better to regard them for the present as belonging to this system, and Professor de Lapparent considers them an undoubted equivalent of the Valenginian ; they are not more than 35 feet thick.

The overlying clays form the zone of *Actinocamax jaculum*, and are about 120 feet thick. It appears to be divisible into three subzones characterised by Ammonites, which in succeeding order are *Hoplites regalis*, *Olcostephanus speetonensis*, and *Olc. Decheni*. Besides these, *Crioceras Duvali*, *Pecten cinctus*, *Meyeria ornata*, and many other fossils occur. The whole of this zone appears to be older than the Atherfield Clay, the lower part, zone of *Hoplites regalis*, represents the Hauterivian, while the higher and greater part represents the Barremian of the Alpine series.

The highest part of the Speeton clay consists of gray and black pyritous clays containing *Actinocamax brunsvicensis* (= *Bel.*

semicanaliculatus), *Hoplites Deshayesi*, a large *Crioceras*, *Arca securis*, *Isocardia angulata*, and others. These beds are clearly equivalent to the Vectian of Southern England ; their total thickness is more than 150 feet, and may be 180, and they are succeeded by gritty clays of Gault age containing *Belemnites minimus*.

In Lincolnshire the Lower Cretaceous beds emerge from beneath the Upper near Caistor, and extend thence in a gradually widening strip to the neighbourhood of Spilsby and Candlesby at the southern end of the Lincolnshire Wolds. The succession of beds found in this district is shown in Fig. 139, and the full thickness does not exceed 200 feet.

The Spilsby Sandstone has a bed of derived phosphatic nodules at the base resting on the Kimeridge Clay. Above are soft yellow and gray sands, including large masses or doggers of calcareous sandstone, which are rich in fossils and yield *Belemnites lateralis*, *Olcosteph. subditus*, *Olc. plicomphalus*, *Trigonia ingens*, *T. robinaldina*, etc. The Claxby and Hundlesby ironstones also appear to belong to this zone, as they have yielded *Bel. lateralis*, *Am. Beani*, *Olc. gravesiformis*, *Astarte senecta*, *Trigonia ingens*, *Rhynchonella multiformis*, *Terebratula sella*.

The Tealby clays are from 40 to 100 feet thick, and represent the zone of *Act. jaculum*, yielding that fossil with *Am. speetonensis*, *Crioceras Duvali*, and *Perna Mulleti*. The Tealby limestone contains *Act. brunsvicensis*, *Exogyra sinuata*, *Pecten cinctus*, and appears to pass southward into a ferruginous oolitic marl, locally called "roach." Above these calcareous beds is the Carstone, which has not yielded any fossils except at its junction with the red chalk, where *Bel. minimus* and *Terebratula biplicata* occur.

In Norfolk the thickness of the series is rather less than in Lincolnshire. The Sandringham Sands consist of light-coloured sands with some beds of brown flaggy sandstone in the upper part ; they have not yielded determinable fossils, and are not like the Spilsby Sands ; hence it is more likely, as Mr. Lamplugh suggests, that they represent the Tealby Clay. The Snettisham Clay contains *Act. brunsvicensis*, and appears to be the equivalent of the Tealby Limestone, but it is nowhere more than 20 feet thick and thins out southward.

The Carstone of this country is a brown ferruginous grit, often cemented by oxide of iron into a sandstone capable of being used as a building stone. Its thickness is about 40 feet, and it is only at its base that fossils have been found. Some of these occur as phosphatic nodules which may or may not be derived, others occur in concretionary lumps of hard grit, and include *Acanth. cornuelianus*, *Trigonia scapha*, *Perna Mulleti*, *Isocardia angulata*, and

Cardium subhillanum, species which prove that this part of the Carstone is of Lower Cretaceous age and on about the same horizon as the Hythe Beds. Hence we may infer that the Carstone of Lincolnshire is of the same age.

B. UPPER CRETACEOUS SERIES

As stated on p. 394, the members of this series have a far wider extension than those of the lower series; they extend southward below the English Channel into France, they pass eastward beneath the eastern counties of England, and below the floor of the North Sea into Belgium and Holland. The following is a tabular view of the stages and zones into which the English series is divisible, with the names of the corresponding French stages :—

Stages.	Zones.	French Divisions.
Upper Chalk	Zone of Ostrea lunata	Senonian.
	Zone of Belemnitella mucronata	
	Zone of Actinocamax quadratus	
	Zone of Marsupites	
	Zone of Micraster coranguinum	
	Zone of Micraster cortestudinarium	
Middle Chalk	Zone of Holaster planus	Turonian.
	Zone of Terebratulina gracilis	
	Zone of Rhynchonella Cuvieri	
Lower Chalk	Zone of Holaster subglobosus	Cenomanian.
	Zone of Ammonites varians	
Selbornian	Zone of Pecten asper	Albian.
	Zone of Ammonites rostratus	
	Zone of Ammonites interruptus	
	Zone of Ammonites mammillatus	

Characteristic Fossils

The following are some of the species which are characteristic of each of the four stages or subdivisions of the Upper Cretaceous series :—

Fossils of the Selbornian

Porifera. Chenendopora Michelini, Doryderma Benettiæ, Siphonia tulipa, Trematocystia Orbignyi.

Hydrozoa. Parkeria sphærica.

Actinozoa. Bathycyathus Sowerbyi, Cyclocyathus Fittoni, Trochocyathus conulus.

Echinoderma. Cardiaster fossarius, Cidaris gaultina, Echinospatagus murchisonianus, Cottaldia Benettiæ, Pentacrinus Fittoni.

Annelida. Serpula concava, Ditrupa difformis.

Crustacea. Etyns Martini, Necrocarcinus Bechei, Palæocorystes Stokesi, Hoploparia longimana.

Brachiopoda. Terebratula biplicata, Terebratella pectita, Rhynchonella dimidiata, Lingula subovalis.

Lamellibranchia. Arca carinata, Cardium gentianum, Inoceramus sulcatus, I. concentricus, Lima parallela, Exogyra conica, Ostrea vesiculosa, Nucula pectinata, Cucullæa glabra, Pectunculus umbonatus, Pleuromya mandibula, Plicatula gurgitis (=P. pectinoides), Trigonia aliformis.

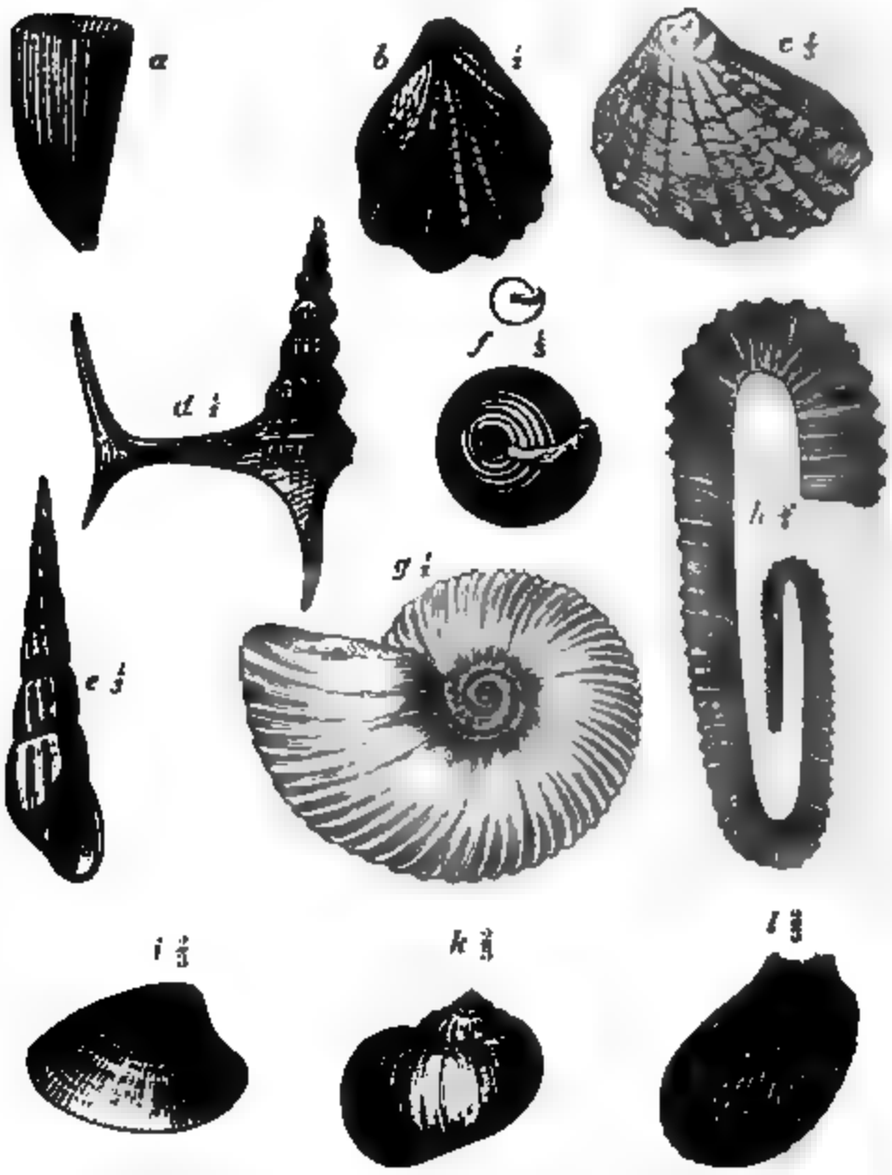

Fig. 141.—GROUP OF SELBORNIAN FOSSILS (GAULT).

a. Trochocyathus conulus.
b. Inoceramus sulcatus.
c. Plicatula gurgitis.
d. Aporrhais carinata.
e. Scalaria gaultina.
f. Bellerophina minuta.
g. Hoplites splendens.
h. Hamites attenuatus.
i. Nucula pectinata.
k. Natica gaultina.
l. Lima parallela.

Gastropoda. Aporrhais carinata, A. Parkinsoni, Natica gaultina, Dentalium decussatum, Bellerophina minuta, Solarium ornatum, Scalaria gaultina, Turritella granulata.

Cephalopoda. Am. (Douvilleiceras) mammillatus, Am. (Hoplites) interruptus, Am. (Hoplites) lautus, Am. (Hoplites) splendens, Am. (Hoplites) auritus, Am. (Schlœnbachia) rostratus, Am. (Schlœnbachia) varicosus, Hamites attenuatus, Nautilus clementinus, Belemnites minimus.

The following are common species which occur both in the Selbornian and the Lower Chalk (Cenomanian) :—

Elasmostoma consobrinum, Catopygus columbarius, Holaster lævis, Salenia petalifera, Peltastes clathratus, Pseudodiadema variolare, Ps. ornatum, Discoidea subuculus, Kingena lima, Rhynchonella grasiana, Lima globosa, Pecten asper, P. orbicularis, P. hispidus, Ostrea vesicularis, Avicula gryphæoides, Nautilus elegans.

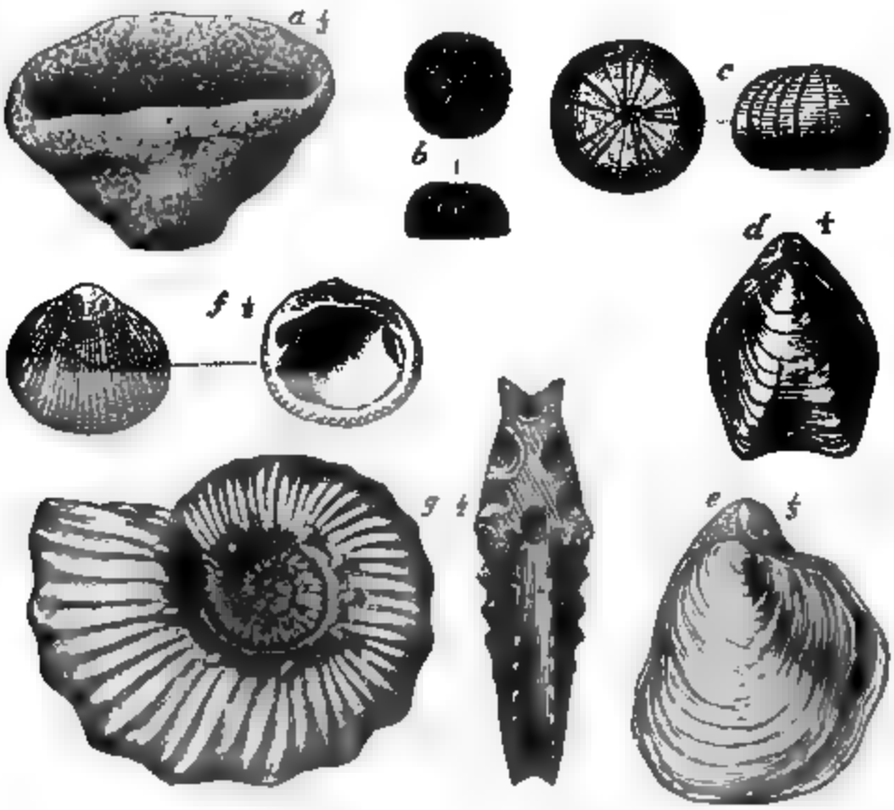

Fig. 142.—GROUP OF SELBORNIAN FOSSILS.

a. Cheneudopora expansa.
b. Micrabacia coronula.
c. Cottaldia Benettiæ.
d. Terebratula biplicata.
e. Exogyra columba.
f. Pectunculus sublævis.
g. Ammonites (Hoplites) auritus.

Fossils of the Lower Chalk

Porifera. Stauronema Carteri, Plocoscyphia labrosa, P. fenestralis.
Actinozoa. Micrabacia coronula.
Echinoderma. Discoidea cylindrica, Cidaris vesiculosa, Holaster, subglobosus, H. trecensis.

Annelida. Serpula umbonata, S. annulata.
Crustacea. Enoploclytia brevimana.
Brachiopoda. Rhynchonella Martini, R. mantelliana, Terebratula semiglobosa, Terebratulina nodulosa.
Lamellibranchia. Cucullæa mailleana, Inoceramus latus, Lima aspera, Pecten elongatus, P. fissicosta, Plicatula inflata, Spondylus striatus, Unicardium ringmeriense.
Gastropoda. Aporrhais Mantelli, Avellana cassis, Dentalium majus, Solarium bicarinatum.

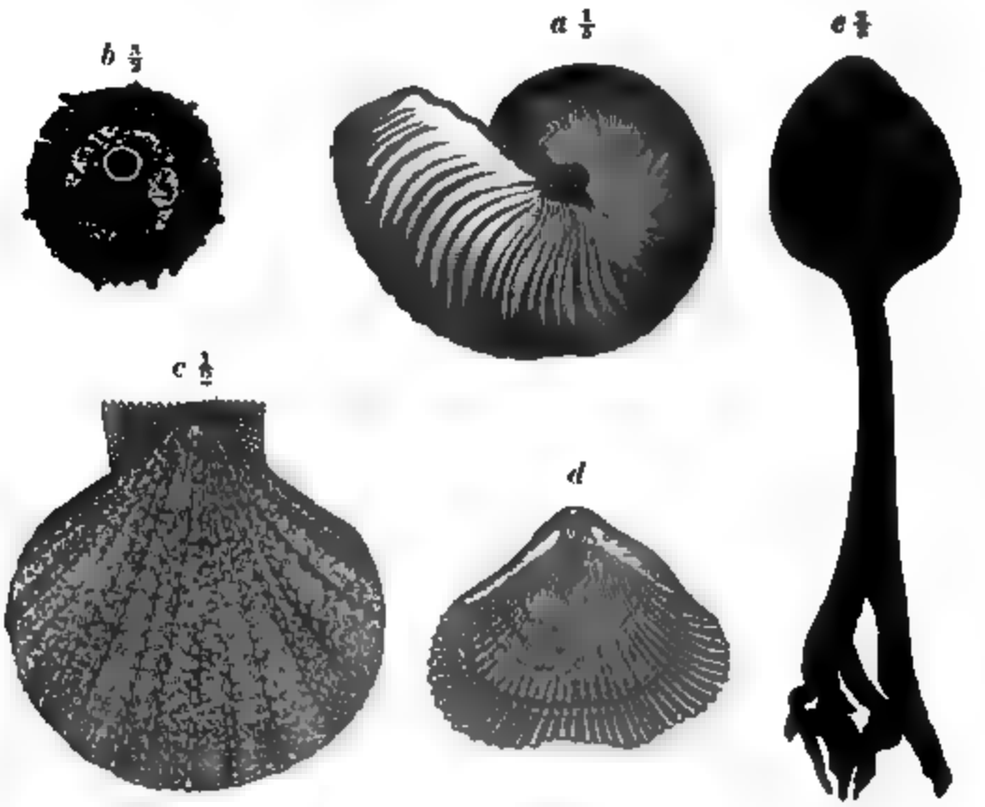

Fig. 143.—GROUP OF NEOCOMIAN FOSSILS (GREENSANDS).
a. Nautilus elegans.
b. Salenia petalifera.
c. Pecten asper (young).
d. Rhynchonella dimidiata.
e. Siphonia pyriformis.

Cephalopoda. Ammonites (Schlœnbachia) varians, Am. (Acanthoceras) rotomagensis, Am. (Acanthoceras) Mantelli, Turrilites costatus, T. Morrisi, Scaphites æqualis, Baculites baculoides, Actinocamax plenus.

Fossils of the Middle Chalk

Echinodermata. Galerites (Echinoconus) subrotundus, Cardiaster pygmæa, Discoidea Dixoni, Cidaris hirudo.
Brachiopoda. Terebratula semiglobosa, Rhynchonella Cuvieri, Terebratulina lata (=gracilis of most authors).
Lamellibranchia. Inoceramus mytiloides (labiatus), I. Cuvieri.
Cephalopoda. Am. (Acanthoceras) nodosoides, Am. (Pachydiscus) peramplus, Am. (Prionotropis) Woolgari.

Fossils of the Upper Chalk (lower zones)

Porifera. Camerospongia campanulata, Doryderma ramosum, Ventriculites impressus, V. mammillaris.

Echinoderma. Cidaris clavigera, C. perornata, Cyphosoma radiatum, Holaster planus, Micraster Leskei (=breviporus), M. præcursor, M. cortestudinarium, M. coranguinum, Epiaster.

Lamellibranchia. Inoceramus involutus, I. Brongniarti, Lima Hoperi, L. granosa, Plicatula Barroisi.

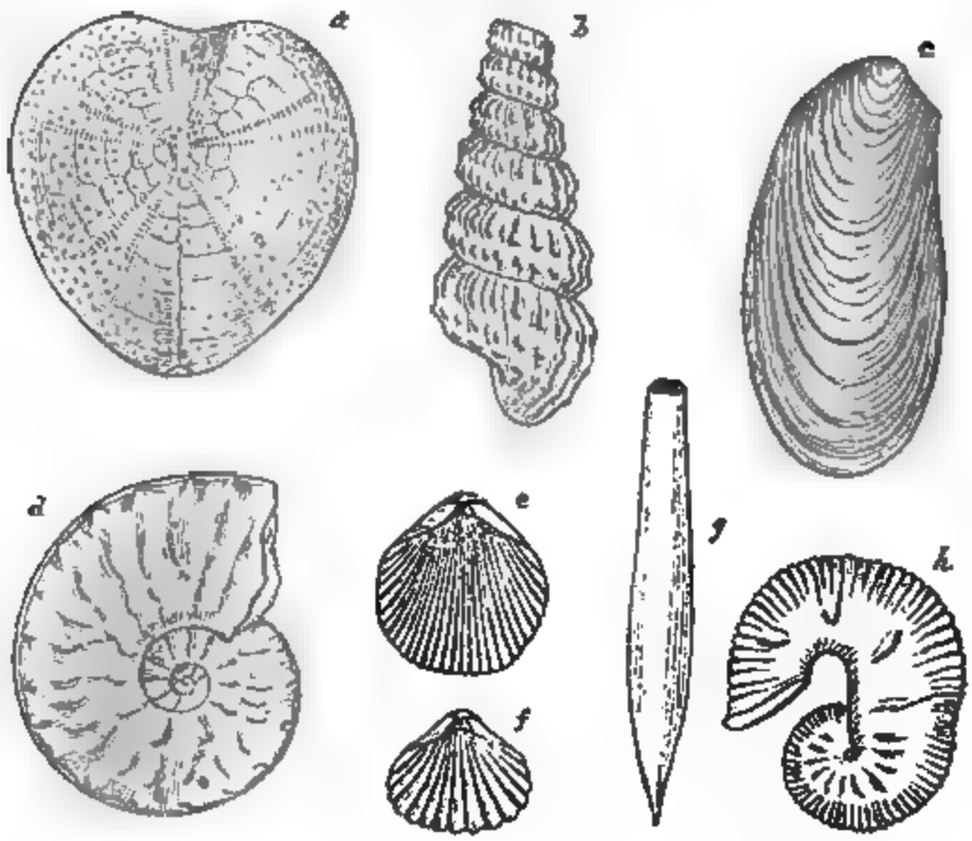

Fig. 144.—GROUP OF LOWER AND MIDDLE CHALK FOSSILS.

a. Holaster subglobosus, ⅔.
b. Turrilites costatus, ½.
c. Inoceramus mytiloides, ⅓.
d. Am. (Schlœnbachia) varians, ½.
e. Rhynchonella Cuvieri, nat. size.
f. ,, mantelliana, ⅔.
g. Actinocamax plenus, ⅔.
h. Scaphites æqualis, ⅓.

Gastropoda. Turbo gemmatus, Trochus Schlüteri, Cerithium Saundersi.

Cephalopoda. Heterocoras reussianum, Scaphites Geinitzi, Baculites bohemicus.

Fossils of the Upper Chalk (higher zones)

Porifera. Coeloptychium agaricioides, Plinthosella squammosa, Scytalia radiciformis, Siphonia Kœnigi, Stichophyma tumidum.

Anthozoa. Caryophyllia cylindracea, Cœlosmilia laxa, Parasmilia Fittoni.

Echinoderma. Cardiaster ananchytis, Galerites (Echinoconus) abbreviatus, Offaster pilula, Marsupites testudinarius, Micraster coranguinum.

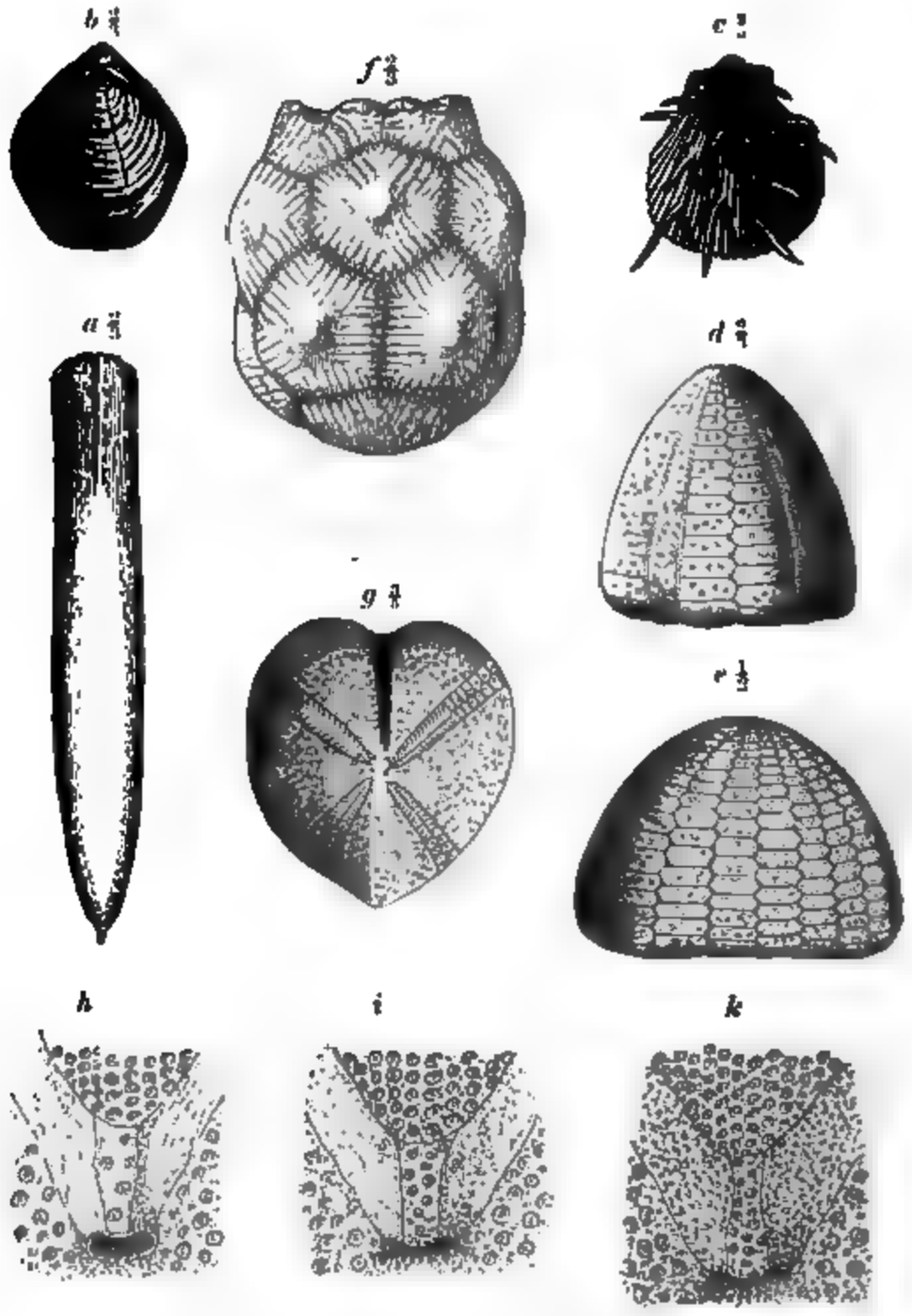

Fig. 145.—GROUP OF UPPER CHALK FOSSILS.

a. Belemnitella mucronata.
b. Terebratula carnea.
c. Spondylus spinosus.
d. Galerites conicus.
e. Echinocorys vulgaris.
f. Marsupites testudinarius.
g. Micraster coranguinum.
h. ,, Leskei (base).
i. ,, præcursor (base).
k. ,, coranguinum (base).

Brachiopoda. Rhynchonella limbata, Magas pumilus, Crania costata, Terebratulina Rowei, T. gracilis.
Lamellibranchia. Ostrea acutirostris, O. curvirostris, O. lunata, O. wegmaniana, Pecten Nillsoni, P. nitidus (=cretosus), Spondylus dutempleanus.
Cephalopoda. Am. (Haploceras) leptophyllus, Actinocamax quadratus, Act. granulatus (=Merceyi), Belemnitella mucronata, B. lanceolata.

Besides the above, the following are more or less common throughout the Upper Chalk :—

Porifera. Heterostinia obliqua, Ventriculites decurrens, V. radiatus.
Anthozoa. Parasmilia centralis, Axogaster cretacea.
Echinoderma. Echinocorys (=Ananchytes) vulgaris, Galerites (Echinoconus) conicus, Cidaris sceptrifera, Cyphosoma Kœnigi.
Brachiopoda. Terebratula carnea, Rhynchonella plicatilis, Rh. reedensis.
Lamellibranchia. Ostrea semiplana, Spondylus spinosus.

Stratigraphy

In describing the Upper Cretaceous rocks we may deal with them under the same three heads as in the case of the Lower Cretaceous.

1. *Southern England*

Selbornian.—This stage includes the deposits which have long been known as Gault and Upper Greensand, names which date from a time when a Middle Cretaceous series was supposed to exist, comprising the Lower Greensand, the Gault, and the Upper Greensand, which were supposed to occur in regular upward succession. As the palæontology of these deposits was more carefully studied it was seen that the "Lower Greensand" was a distinct stage, but that the Upper Greensand was inseparable from the Gault, and was to a large extent merely a sandy facies of the Gault. Hence it became necessary to combine these two facies under one name as a single stage. For this the name *Selbornian* has been chosen from the village of Selborne in Hampshire, and though the names Gault and Greensand are convenient terms for different lithological types, the student must be warned against the error, perpetuated by the use of these names, that the Upper Greensand is a definite subdivision newer than the Gault.[9] Where the stage is complete four zones can be distinguished. These are :—

4. Zone of *Pecten asper* and *Cardiaster fossarius.*
3. Zone of *Ammonites* (*Schlœn.*) *rostratus* (=*inflatus*).
2. Zone of *Am.* (*Hoplites*) *lautus* and *Am.* (*H.*) *interruptus.*
1. Zone of *Am.* (*Douvilleiceras*) *mammillatus.*

Of these zones the lowest is always a sand, the second is generally

CORRELATION TABLE OF CRETACEOUS ROCKS

Kent.	Isle of Wight.	South Wiltshire.	Cambridge and Suffolk.	Yorkshire.	Ireland.
Upper Chalk, B. Belemnite zones, 100 feet. A. Micraster zones, 400 feet.	Upper Chalk, Belemnite zones, 800 feet. Micraster zones, 350 feet.	Upper Chalk, Belemnite zones, 500 feet. Micraster zones, 300 feet.	Upper Chalk, Belemnite zones, ?200 feet. Micraster zones, 300 feet.	Upper Chalk, Belemnite zones, 650 feet. Micraster zones, 300 feet.	Upper Chalk, Belemnite zones, 100 feet. Micraster zones, 10 to 25 feet.
Middle Chalk, 240 feet.	Middle Chalk, 160 to 200 feet.	Middle Chalk, 100 feet.	Middle Chalk, 320 feet.	Middle Chalk, ?160 feet.	? Absent.
Lower Chalk, 200 feet.	Lower Chalk, 200 feet.	Lower Chalk, 250 feet.	Lower Chalk, 170 feet.	Lower Chalk, 130 feet.	Irish greensands, 30 to 50 feet.
Lower and Upper Gault (Selbornian), 120 feet.	Selbornian sand and clay, 180 to 275 feet.	Selbornian sands and clay, 250 feet.	Gault, 180 to 90 feet.	Red Chalk, 2 to 30 feet.	Absent.
Vectian beds, 240 feet.	Vectian beds, 800 feet.	Vectian sands, 60 feet.	Vectian sands, 50 feet.	Upper Speeton clay, 150 feet.	
Wealden, 1000 feet.	Wealden, probably 2000 feet.	Wealden, 100 feet (only in Vale of Wardour).	Absent.	Middle and Lower Speeton clays, 185 feet.	

clay (*i.e.* Gault), the third may be "Gault," or malmstone, or gray sands; the fourth is always green sand or sandstone.

At Folkestone in Kent the three lower zones are found, but the highest does not exist, the so-called Upper Greensand of that place being the chloritic marl or zone of *Stauronema Carteri* at the base of the Lower Chalk. The zone of *Am. rostratus* is known as the Upper Gault, and consists of pale gray marly clay about 78 feet thick; this includes a bed of dark green glauconitic sand in the upper part, and is separated from the Lower Gault by a layer of phosphatic nodules. These beds yield *Am.* (*Schlœnbachia*) *rostratus*, *Sch. Goodhalli*, *Pecten raulinianus*, *Terebratula biplicata* in the upper part, *Am.* (*Sch.*) *varicosus* and *Inoceramus sulcatus* in the lower part. The "Lower Gault" consists of gray clays with several bands of phosphatic nodules and a layer of such nodules at the base embedded in dark green glauconitic sand. The characteristic fossils are *Hoplites interruptus*, *H. splendens*, *H. lautus* (upper part), *Lima parallela*, *Pinna tetragona*, *Inoceramus concentricus*. Below and forming the base of the stage are 5 or 6 feet of coarse green sand containing *Douvilleiceras mammillatus*.

Inland the thickness of the Gault becomes much greater and is about 200 feet near Maidstone. This increase appears to be chiefly in the Upper Gault, for the lower division does not exceed 50 feet in any part of Kent. It is not till we reach Westerham that the so-called "Upper Greensand" makes its appearance at the top of the Gault, and thence it thickens westward through Surrey. This deposit is known in Surrey as "firestone" and "hearthstone," and in Hampshire as "malmstone"; it is a greenish gray siliceous stone consisting partly of fine sand and glauconite grains, partly of sponge spicules and globular colloid silica, and it passes down into sandy marls which are clearly part of the Upper Gault.

In Hampshire, near Alton and Selborne, the general succession is as follows:—

	Feet.
5. Soft greenish sands without fossils . . .	2 to 15
4. Malmstone with beds of calcareous stone . .	80 to 100
3. Sandy marls with *Am. rostratus* and *Inoc. sulcatus*	30 to 50
2. Dark clays with *Am. interruptus*	about 100
1. Green sands with phosphatic nodules . . .	3 to 15
	About 240

From the malmstone *Am.* (*Schlœnbachia*) *rostratus*, *Am.* (*Hoplites*) *auritus*, *Anisoceras armatum*, *Arca carinata*, and *Pleuromya mandibula* have been obtained, and there is no doubt that it represents the greater part of the Upper Gault of Folkestone.

When the beds crop out again in Wiltshire there are still clays and marls in the lower part, but they belong entirely to the Lower Gault (about 90 feet). They are succeeded by soft malmstones with *Schlœnb. rostrata*, *S. varicosa*, *Pleuromya mandibula*, *Cardium gentianum*, and other fossils. These are succeeded by 30 to 60 feet of greenish gray sands, often containing nodules and layers of chert, and having a special fauna, of which the commonest are *Pecten asper*, *P. Galliennei*, *Neithea quadricostata*, *Lima semisulcata*, *Cardiaster fossarius*, *Epiaster Lorioli*, and *Discoidea subucula*. These beds are well developed near Warminster, whence they are sometimes called the Warminster Beds, and they are succeeded by soft green sand with calcareous concretions and many fossils which forms a passage up into the chloritic marl.

A similar succession is found in the southern part of the Isle of Wight, where the beds are :—

		Feet.
P. asper zone	Sands and chert beds (few fossils) . .	about 30
Am. rostratus zone	Soft sandstones and sandy malm . .	,, 70
	Dark gray sandy clays . . .	,, 45
Lower Gault	Blue clays with *Am. denarius*, etc. .	,, 100

The "Gault" passes down into the "Carstone" (see p. 414), which Mr. A. Strahan is inclined to regard as representing the zone of *Am. mammillatus*, but that fossil has not yet been found, and the question remains undecided.

In South Dorset the succession is similar, but the base of the Selbornian is sharply defined by a thin layer of quartz pebbles, while the Lower Gault becomes more and more sandy as it is traced westward. Ammonites also become very rare in it, but *Lima parallela*, *Pinna tetragona*, *Nucula pectinata*, and *Pleuromya plicata* occur. The zone of *Am. rostratus* consists of green sands with beds of calcareous sandstone, and there is always a well-marked zone of *Pecten asper* at the top.

In Devon the beds are well exposed in the cliffs between Lyme Regis and Sidmouth, the base of the Selbornian gradually passing over the Lower Lias and across the Keuper marls till it rests on the Keuper sandstones. At the base near Lyme and Axmouth there are still some few feet of clay (Lower Gault), but westward this either thins out or passes into sand. At Beer and near Beer Head the succession is as follows :—

	Feet.
3. Hard calcareous sandstone	8 to 10
2. Sands and sandstones with more or less chert . . .	about 60
1. Soft gray sands passing down into dark green clayey sand .	,, 90

Of these divisions the lowest appears to represent the Upper

Gault or zone of *Am. rostratus*, while the two upper must correspond to the zone of *Pecten asper*. So local is the occurrence of this Pecten, however, that no specimen has yet been found in these sandstones, its place being taken apparently by large *Exogyræ*, *E. digitata*, and *E. columba*.

At Sidmouth and in the Blackdown Hills the lower sands have yielded a rich fauna, the shells being preserved in chalcedony, and the following are some of the commonest species, *Am. varicosus*, *Aporrhais calcarata*, *Turritella granulata*, *Protocardia hillana*, *Cucullæa glabra*, *Cytherea plana*, *Lucina orbicularis*, *Trigonia aliformis*, and *Tr. scabricola*.

An outlier of the Selbornian sands occurs on the Haldon Hills about 12 miles south-west of Sidmouth. Here they rest on the red Permian breccias, and are reduced to a thickness of 70 or 80 feet. The lower 55 feet contain many of the Blackdown fossils, and are clearly of the same age ; they are overlain by yellowish sand with lumps of chert, above which is coarser sand containing rounded grains of tourmaline which have doubtless been derived from the granite of Dartmoor.

Lower Chalk.—This stage as developed in the south of England is divisible into two parts or zones, the lower part forming the zone of *Am.* (*Schlœnbachia*) *varians*, and the higher part that of *Holaster subglobosus*. At the base, and included in the range of *Am. varians*, is the subzone of *Stauronema Carteri*, consisting of sandy glauconitic chalk which is often called the "Chloritic Marl." At the top is a band of soft gray marl which is often called the Belemnite marl or subzone of *Actinocamax plenus*, from the presence of that Belemnoid.

At Folkestone the beds composing the Lower Chalk are :[10]—

		Feet.
Zone of *Hol. subglobosus*, 126 feet	7. Belemnite marl (with *Act. plenus*) . .	6
	6. Whitish chalk in massive beds (few fossils) .	60
	5. Gray chalk in massive beds . . .	60
Zone of *Am. varians*, 68 feet	4. Gray marly chalk	20
	3. Alternating beds of gray marl and hard gray chalk	22
	2. Gray chalk with reefs of sponges . .	10
	1. Soft green glauconitic chalk (*Stauronema*) .	16
		194

Beds 2, 3, and 4 are characterised by *Sch. varians*, *Acanth. rhotomagensis*, *Ac. Mantelli*, *Turrilites costatus*, *Pecten elongatus*, *Rhynchonella Martini*, *R. mantelliana*, and the sponges *Plocoscyphia labrosa* and *P. fenestralis* in No. 2. No. 5 contains *Holaster subglobosus*, *Discoidea cylindrica*, and a few other fossils, and the teeth

of *Ptychodus decurrens* are not uncommon in Nos. 6 and 7. The Lower Chalk exhibits a similar facies, and maintains the same thickness all round the Wealden area, and is exposed in many large quarries along its outcrop in Kent and Surrey, especially in the valley of the Medway.

The Lower Chalk attains its greatest thickness in Wiltshire, where it is about 250 feet, the greater part belonging to the zone of *Am. varians*, which includes beds of a peculiar siliceous chalk containing imperfect flints.

In the Isle of Wight the best exposure of the Lower Chalk is in the Culver Cliffs north of Sandown (see map, Fig. 146), where the following succession is seen :—

		Feet.
Zone of *Hol. subglobosus*	Soft bluish gray marl	6
	Massive smooth whitish chalk	86
Zone of *Am. varians*	Beds of gray chalk alternately hard and soft	45
	Gray marly chalk with layers of hard chalk	40
	Bluish gray marl with reefs of *Plocoscyphia*	27
	Chloritic marl with phosphatic nodules	8
		212

The Chloritic Marl is from 6 to 8 feet thick along the Undercliff (Ventnor, etc.), and abounds in phosphatised casts of *Schlœnbachia varians*, *Acanth. Mantelli*, *Turrilites Morrisi*, and *Cucullæa mailleana*, together with shells of *Pecten asper*, *Rhynchonella grasiana*, and the sponge *Stauronema Carteri*. The two main zones are here less clearly marked than in Kent and Surrey, for *Hol. subglobosus* occurs in both, and few other fossils can be found in the higher beds, so that the limit can only be judged by the upward range of *Am. varians* and other lower-zone fossils.

In Dorset there is a more decided break between the Selbornian and the Lower Chalk ; the basement bed is a glauconitic chalk with phosphatic nodules and fossils, but it does not seem to be the equivalent of the Chloritic Marl, for it does not contain *Stauronema*, while it has other fossils which in the Isle of Wight are common from 10 to 20 feet above the Chloritic Marl, such as *Scaphites æqualis*, *Acanthoceras rotomagensis*, *Turrilites Wiesti*, and *Holaster subglobosus*. Other common fossils are *Cucullæa mailleana*, *Unicardium ringmeriense*, and *Galerites castanea*. The thickness of the Lower Chalk is also less (140 feet near Swanage), diminishing westward till it is only about 60 feet in West Dorset.

The Dorset facies of the Lower Chalk can be traced inland by Bridport, Beaminster, and Crewkerne to Chard in Somerset, where it is still about 60 feet thick with a highly fossiliferous bed at the base ; but when it reappears on the coast near Lyme and Seaton

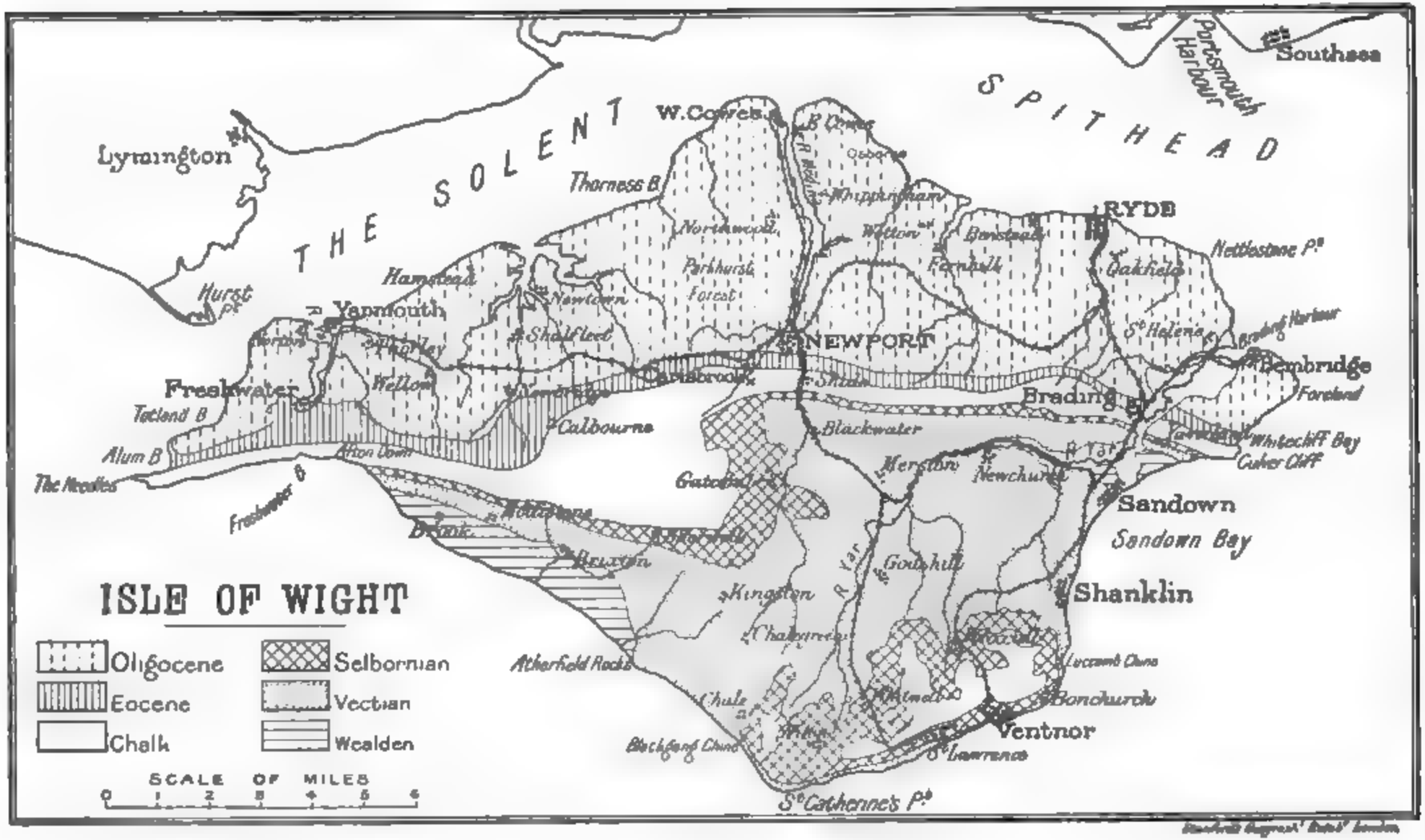

Fig. 146.—GEOLOGICAL MAP OF THE ISLE OF WIGHT.

it has undergone such a change that it ceases to be chalk, and is reduced to a thin band of calcareous sandstone enclosing large grains of quartz. Near Lyme this bed is only 3 or 4 feet thick, but at Beer Head it swells out into two beds which have a combined thickness of 18 feet, and are highly fossiliferous. We could not expect a coarse grit to contain the same assemblage of fossils as a chalk, and it is interesting to find the fossils in these calcareous grits are similar to those found in the sandy Cenomanian deposits of Western France.[11]

That this Cenomanian of Devon is equivalent to the English zone of *Am. varians* is shown by the presence of that species, and all the other common Chalk Marl Ammonites, Turrilites, and Nautili, with *Scaphites æqualis*, *Holaster subglobosus*, and *Galerites castanea*, while among the fossils which connect it with the Cenomanian of France are *Trigonia vicaryana*, *Pecten asper*, *P. puzosianus*, *P. subacutus*, *Lima tecta*, *Terebratula tornacensis*, *T. capillata*, *Terebratella pectita*, *Cottaldia Benettiæ*, and *Catopygus columbarius*. Some of these occur also in England in the topmost beds of the Selbornian, just below the subzone of *Stauronema Carteri*. Curiously enough this sponge has not been found in Devon, though *Elasmostoma* and *Trematocystia* are not uncommon.

Middle Chalk.—Until recently this stage has been considered to include three zones, the lowest being characterised by the abundance of *Rhynchonella Cuvieri*, the second by a *Terebratulina* hitherto known as *T. gracilis*, but more correctly as *Ter. lata*, and a third zone of *Holaster planus*. But as many of the species occurring in the *H. planus* zone range into the Upper Chalk, it has been found more convenient to draw the line of division where most of these species set in, thus leaving only two zones in the Middle Chalk. At its base there is always a certain thickness of hard nodular chalk which forms a great contrast to the soft marl on which it rests; this rocky chalk is called the Melbourn Rock from a village in Cambridgeshire.

Commencing as before in Kent, we find a good section of this stage in the cliffs near Dover, which show :—

		Feet.
Zone of *Ter. lata*	Rather rough lumpy white chalk	20
	Smooth white chalk with thin layers of gray marl and several courses of flints	90
	White chalk with seams of marl but no flints . .	60
Zone of *Rh. Cuvieri*	Hard chalk with frequent nodular layers . . .	38
	Hard and rough nodular chalk	32
		240

The fossils in the lower zone are *Rhynchonella Cuvieri*, *Inoceramus*

mytiloides, *Cardiaster pygmæus*, *Galerites subrotundus*, *Discoidea Dixoni*, and its variety *minima*. In the upper zone are *Terebratulina lata*, *Inoceramus Cuvieri*, and *Micraster corbovis*; here too *Spondylus spinosus* makes its first appearance, and *Holaster planus* comes in near the top.

These beds can be traced all round the Wealden area, and another fine exposure of them can be seen in the cliffs of Beachy Head, where, however, there are no flints in the zone of *Ter. lata*.

In the Isle of Wight, Culver Cliff and quarries near Yarbridge exhibit the following succession :—

		Feet.
Zone of *Ter. lata*	Rough chalk with a seam of black clay in the middle and a layer of green-coated nodules near the base	19
	Thick-bedded white chalk with seams of marl	96
Zone of *Rh. Cuvieri*	Hard chalk, becoming nodular below and containing many broken *Inoceramus mytiloides*	70
	Rough nodular chalk with marly veins	8
		183

Westward in Compton Bay the thickness is reduced to 150 feet. In Dorset, at Ballard Cliff, it is only 122 feet, but the same layer of green-coated nodules occurs about 20 feet from the top and has been mistaken for chalk rock. In the bays on the coast of Dorset the chalk is so crushed that measurements are not reliable, but at White Nothe Dr. A. W. Rowe estimates its thickness at 134 feet.[13]

In Devon the Middle Chalk is well exposed near Beer, and is about 100 feet thick, the zone of *Rh. Cuvieri* here including some thickness of hard shelly chalk which is quarried for building purposes, and is known as Beer stone.

Upper Chalk.—The chalk of this division has been divided into seven zones (see p. 421), but the higher zones are not everywhere present, having been removed from large areas in the south of England during the upheaval which preceded the formation of the Eocene deposits. These seven zones may be grouped into two substages, the lower of which, including the zones of *Hol. planus*, *Micraster cortestudinarium*, and *M. coranguinum*, may be termed the Micraster chalk, while the higher zones may be called the Belemnite chalk until more definite names are proposed.

In Kent the Upper Chalk forms the cliffs from St. Margaret's Bay near Dover to Walmer and Deal, and again from Ramsgate round the Isle of Thanet to Margate and Reculvers.

Mr. W. Hill finds a convenient base for the zone of *Holaster planus* in a bed which is full of scattered flints, and in which

Echinocorys vulgaris makes its appearance. Measured from this the thickness of the zone is about 48 feet, and it consists of a succession of beds of rough lumpy chalk, the lumps being very hard but embedded in a softer matrix, and the top is marked by a coarse hard nodular rocky chalk. In these beds *Micraster Leskei*, *M. præcursor*, and *Hol. planus* are common.

They are succeeded by chalk with many flints, whiter and less rough, but still including some hard nodular layers; in this *Micraster præcursor* and its broader variety of *cortestudinarium* are abundant. The thickness is 56 feet according to Dr. Rowe.[12]

The zone of *M. coranguinum* consists of smoother chalk with numerous layers of black flints, also some continuous layers of flint. This zone is said to be 280 feet thick, and it forms the cliffs near Walmer, Ramsgate, and Broadstairs. The low-zone Micrasters die out in the lower 70 feet of this zone, above which *M. coranguinum* takes their place with *Cidaris sceptrifera*, *C. perornata*, *Cyphosoma Kœnigi*, *Galerites conicus*, and several species of *Parasmilia*.

The zone of *Marsupites* or Margate Chalk consists of soft chalk with very few flints and is 116 feet thick at Margate; it is divisible into a lower band in which *Uintacrinus* is common and an upper band in which *Marsupites* is common. Other characteristic fossils are *Ammonites* (*Haploceras*) *leptophyllus*, *Actinocamax verus*, *A. granulatus*, and *Terebratulina Rowei*. This is the highest chalk seen on the Kentish coast, and it is doubtful whether any higher zone occurs in any part of Kent or Surrey.

On the coast of Sussex, however, higher zones come in. The Marsupite zone has recently been identified by Dr. Rowe at Seaford Head, and above it is 170 feet of chalk containing *Offaster pilula*, *Actinocamax granulatus*, *Cœlosmilia laxa*, and other fossils of the *quadratus* zone. This chalk extends westward from Newhaven to Brighton, and thence to the valley of the Arun, where a succession of quarries between Houghton and Arundel shows parts of all the zones above mentioned (see Fig. 147). Still farther west chalk containing *Belemnitella mucronata* has been found, and this highest zone underlies the Eocene of Hampshire and is well exposed in quarries on Portsdown Hill, where an inlier of chalk is brought up within the Tertiary area by an anticlinal flexure. The total thickness of the Upper Chalk in West Sussex and Hampshire must be from 800 to 900 feet.

In the Isle of Wight the thickness of the Upper Chalk is estimated at about 1200 feet, and the following subdivisions have been recognised :—

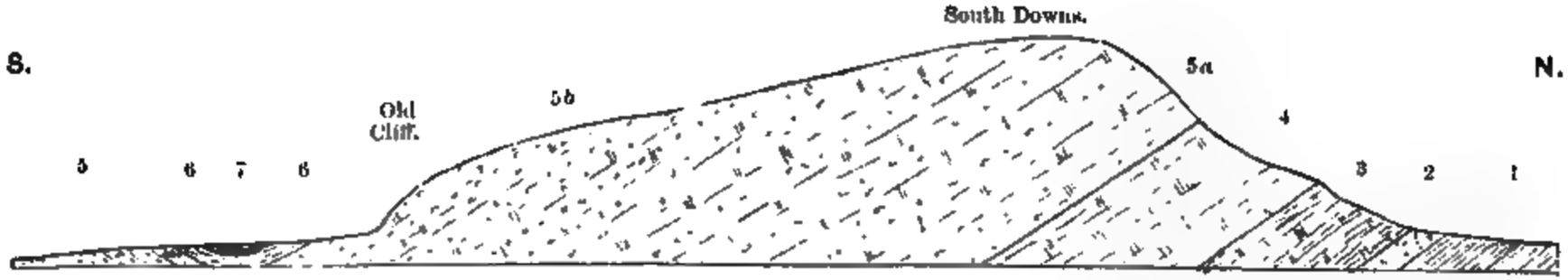

Fig. 147.—DIAGRAMMATIC SECTION ACROSS THE SOUTH DOWNS NEAR ARUNDEL (by C. Reid). Distance about 7 miles. Vertical scale about 500 feet to an inch.

7. London Clay } Eocene.
6. Reading Beds }
5b. *Marsupites* and *A. quadratus* zones } Upper Chalk.
5a. *Micraster* zones }
4. Middle Chalk.
3. Lower Chalk.
2. Malmstone } Selbornian.
1. Gault }

Fig. 148.—SECTION THROUGH CHILTON AND DIDCOT IN BERKSHIRE. Distance 5¼ miles. Vertical scale 1200 feet to an inch.

5. Upper Chalk.
4. Middle Chalk.
3. Lower Chalk.
2. Upper Greensand (sand and malmstone).
1. Lower and Upper Gault.

	Feet.
4. Zones of *Bel. mucronata* and *Act. quadratus* . . .	about 600
3. Zone of *Marsupites testudinarius*	,, 100
2. Zone of *Micraster coranguinum*	,, 400
1. Zone of *Micraster præcursor*, including beds containing *M. cortestudinarium* and *Hol. planus*	,, 80

This chalk forms the greater part of the ridge which crosses the centre of the island, terminating in the Culver cliffs on the east and in the Needles on the west. The cliff sections are not easily accessible, but parts of the series are exposed in the inland quarries.

The same zones with a total thickness of about 1000 feet are found in Dorset, where Dr. Rowe has recently identified the zone of *Marsupites* and has been able to separate the zone of *Act. quadratus* from that of *Bel. mucronata*, assigning a thickness of 354 feet to the former and not less than 250 to the latter,[13] the characteristic fossils of the one being *Actinocamax granulatus*, *Act. quadratus*, and *Offaster pilula*, while those of the higher zone are *Belemnitella mucronata*, *B. lanceolata*, *Cardiaster ananchytis*, *Magas pumilus*, *Crania costata*, and *Rhynchonella limbata*.

2. *Midland District*

As the beds of the Upper Cretaceous series are traced northward from the Vale of Pewsey through Berkshire, Oxfordshire, Buckinghamshire, Bedfordshire, and Cambridgeshire, important changes take place in the lower part of the series, though the zonal divisions of the chalk above are maintained with little alteration. The escarpment of the chalk is a prominent physical feature, forming the front of the Berkshire Downs and of the Chiltern Hills to the northward. The bold outlines of the frontal spurs and ridges of these hills is doubtless due to the hardness of the Chalk Rock and the nodular chalk above it, as these beds invariably form the capping of such ridges.

Selbornian.—This division is fully developed in Berkshire and Oxfordshire and consists of the following members :—

	Feet.
Dark green sand and glauconitic marl	15 to 20
Malmstone with layers of sandy marl	50 to 100
Marls and clays of the "Upper Gault"	} 200
Clays of the "Lower Gault"	

This succession is illustrated in Fig. 148. The base of the Gault is seen at Culham, where it yields the usual fauna of the *Am. interruptus* zone, the upper marls with *Avicula gryphæoides* are exposed in the railway cutting at Didcot, and the malmstones can be seen in the cuttings on the line to Marlborough as well as near Wallingford. The band of green sand at the summit has not yielded fossils, but it probably represents the zone of *Pecten asper*.

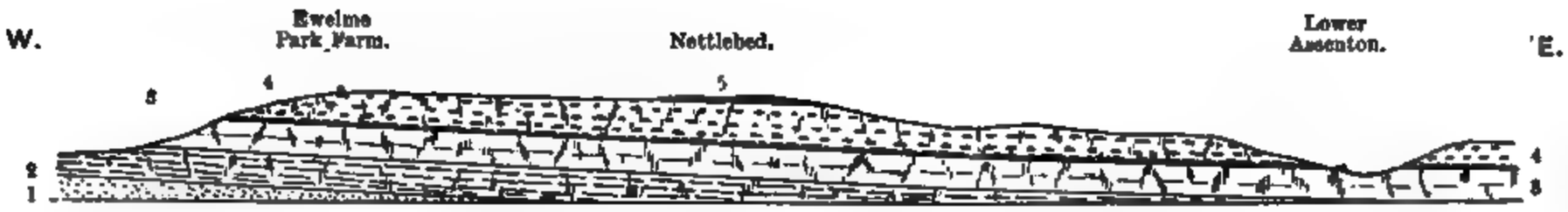

Fig. 149.—SECTION ACROSS THE CHILTERN HILLS FROM NEAR WALLINGFORD TO ASSENTON NEAR HENLEY. Distance about 8 miles.

5. Reading Beds (Eocene).
4. Upper Chalk.
3. Middle Chalk.
2. Lower Chalk.
1. Selbornian (Malmstone and Gault).

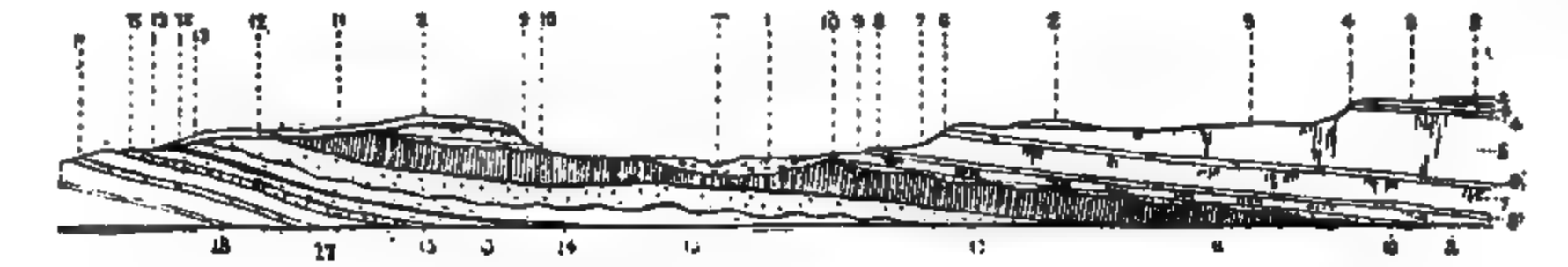

Fig. 150.—SECTION THROUGH CAMBRIDGE AND THE GOG-MAGOG HILLS. Distance about 20 miles. Reduced from the Geological Survey section and reproduced from *Proc. Geol. Assoc.* vol. viii. p. 401.

1. Valley gravel.
2. Boulder-clay.
3. Upper Chalk, and, 4, Chalk Rock.
5. Middle Chalk and, 6, Melbourn Rock.
7, 8, 9. Lower Chalk and, 10, Cambridge Greensand.
11. Gault (Selbornian).
12. Vectian Sands.
13, 14. Kimeridge Clay.
15. Corallian.
16 to 18. Oxfordian.

The Gault forms a continuous band of low-lying clay land throughout the district, and in Buckingham, Bedford, and Cambridge it occupies the greater part of the plain which intervenes between the escarpments of the Chalk and the Lower Greensand. It appears to attain its greatest thickness in Bucks, where the following horizons can be recognised :—[14]

5. Bluish micaceous clays.	Upper Gault, 80 feet.
4. Pale gray calcareous clay	
3. Layer of phosphate nodules mixed with glauconite grains	
2. Stiff dark blue clays	Lower Gault, 150 feet.
1. Slate-coloured clay with layers of nodules near the base.	

The fossils in No. 1 are a mixture of species elsewhere characterising Upper and Lower Gault, *Schlænbachia rostrata* and *cristata* occurring with *Hoplites lautus* and *interruptus*, *Inoceramus sulcatus* with *I. concentricus ; Belemnites minimus* is very abundant. In the upper nodule bed, however, the fossils are all of Upper Gault species, viz. *Schlœnb. rostrata*, *Hoplites splendens*, *H. raulinianus*, *Terebratula biplicata*, and *Avicula gryphæoides*—the same *Avicula* is the principal fossil in the uppermost clays.

Traced to the north-east the Lower Gault thickens to 200 feet, but the Upper Gault is cut out gradually by erosion, and the fossils of the nodule bed (No. 3) are found washed out and *remaniés* at the base of the Chalk Marl in Bedford and Cambridge. In Cambridge, too, the Gault becomes rapidly thinner, and is not more than 90 feet thick near Soham. There is reason to believe, moreover, that this 90 feet includes a portion of the Upper Gault which undoubtedly comes in again beyond the area of erosion in Norfolk, as will hereafter be mentioned.

Lower Chalk.—The following is the constitution of this division all along its outcrop north of the Thames Valley through Berkshire, Bedfordshire, Cambridge, and Suffolk :—

	Feet.
5. Soft gray shaly marl enclosing a band of hard white chalk, *Actinocamax plenus*	3 to 5
4. Tough blocky chalk without distinct bedding, *Holaster subglobosus*, *Acanth. rotomagensis*	60 to 80
3. Totternhoe stone, hard gray sandy chalk, *Rhynch. mantelliana*, *Lima echinata*, *Kingena lima*, *Pecten fissicosta*, etc.	2 to 20
2. Soft marls with occasional layers of hard marly rock in Oxford and Bucks, *Schlœnb. varians*, *Rhynch. Martini*, *Inoceramus latus*	60 to 80
1. Marl with green grains, passing into the nodule bed known as Cambridge Greensand	1 to 2

The Cambridge Greensand commences near Barton-le-Clay

(north of Luton), to which locality the nodule bed in the Gault has been traced, and there can be little doubt that all the nodules and the phosphatised fossils which occur in the Cambridge Greensand have been derived from the erosion and destruction of the Upper Gault. This derived fauna comprises some 210 species of Invertebrata, but about 80 of these have not yet been recognised elsewhere in England; out of the remaining 130 no less than 114 occur in the Gault of Folkestone, most of them and nearly all the commoner fossils occurring in the Upper Gault.[15] The commonest species are *Schlœnb. rostrata*, *Hoplites auritus*, *H. raulinianus*, *Avicula gryphœoides*, *Terebratula biplicata*, *Plicatula gurgitis*, and *Rhynchonella sulcata*, but it is noteworthy that the last is a very rare fossil in the Gault elsewhere.

The Vertebrate fauna of the Cambridge Greensand is very remarkable, the remains of many species of Ichthyosaurs, Plesiosaurs, Dinosaurs, Chelonians, and Pterodactyles having been found, together with bones belonging to a bird (*Enaliornis*). Most of these bones have doubtless been washed out of the Gault, but some may be chalk marl forms.

The indigenous fauna of the Cambridge Greensand is found in the marly matrix of the bed, and some of the species are *Vermicularia umbonata*, *Discoidea subucula*, *Micrabacia coronula*, *Rhynchonella lineolata*, *Kingena lima*, and *Terebratulina triangularis*, most of which occur also in the Chalk Marl above.

Another speciality of this district is the Totternhoe stone, so named from a place near Dunstable, where it is 20 feet thick, and is quarried for building purposes. It varies greatly, however, in thickness, and is sometimes represented by two beds of sandy stone, with chalk marl between them. At its base there is usually a layer of green-coated phosphatic nodules, and small fragments of phosphate are common in the stone above.

This Totternhoe stone forms the base of the *Holaster subglobosus* zone, and that fossil is occasionally found in it, as are also *Acanth. rotomagensis* and *Ac. cenomanensis*, though they are much more common in the chalk above. The *Hol. subglobosus* zone consists of gray chalk in the lower part, and whitish chalk in the upper part; its thickness appears to vary, as if it had suffered from contemporaneous erosion during the deposition of the shaly marl which overlies it.

Middle Chalk.—This division exhibits the same lithological and palæontological characters as in the south of England. In Berkshire it is not more than 150 feet, but north of the Thames it rapidly thickens to about 220 feet, and maintains this thickness into Suffolk.

The Melbourn rock at the base is from 8 to 10 feet thick, and consists of hard nodular chalk; it passes up into bedded chalk, in which *Inoceramus mytiloides* and *Rhynchonella Cuvieri* are generally abundant.

The higher zone consists of soft white chalk with layers of gray shaly marl and occasional nodules of flint, which become more numerous towards the north, till in Cambridge and Suffolk flints are frequent in this zone and are often of elongate finger-like form. Fossils are seldom abundant, but *Galerites subrotundus* and *Terebratulina lata* occur, with *Spondylus spinosus*, *Holaster planus*, and *Micraster corbovis* in the higher part.

Upper Chalk.—Throughout the inland outcrop the zone of *Holaster planus* is represented by several beds of very hard compact subcrystalline chalk, generally of a creamy colour, and each bed having a layer of green-coated calcareo-phosphatic nodules at the top. This rock is known as the "Chalk Rock." Sometimes there are six or seven such beds, sometimes only two or three, succeeded by loose chalk consisting of hard lumps in a soft matrix. Very frequently these beds contain grains of glauconite; they are generally full of fossils, and among these Gasteropods are noticeable, for these are rarely found either in Middle or Upper Chalk. The most characteristic fossils are *Pachydiscus peramplus*, *Prionocyclus Neptuni*, *Scaphites Geinitzi*, *Heteroceras reussianum*, *Turbo Geinitzi*, and *T. gemmatus*. *Holaster planus*, *Micraster præcursor*, and *M. Leskei* are also common. The thickness of this Chalk Rock and of the associated nodular chalk nowhere exceeds 26 feet, but is often less.

White chalk with frequent layers of flints and occasional beds of hard chalk succeeds, and appears to represent the zone of *Micraster cortestudinarium*, but fossils are rare, and this zone passes up into similar chalk containing *M. coranguinum*, *Echinoconus conicus*, and spines of *Cidaris sceptrifera*, *C. perornata*, etc. Flints are very numerous and often hollow with remains of *Doryderma ramosum* and other sponges. Both these zones are distinguishable in the valley of the Thames between Streatley and Reading. In Cambridgeshire the chalk of Balsham and Stetchworth belongs to the *cortestudinarium* zone, while that round Haverhill and Bury St. Edmunds belongs to the *coranguinum* zone.

The zone of *Marsupites* has not yet been identified with certainty in any part of the area under description, but some remarkable beds are exposed at Taplow near Maidenhead which belong either to this zone or to that of *Actinocamax quadratus*. A large quarry about 60 feet deep shows white chalk without flints, but including two beds of brown phosphatic chalk, each resting on a bed of hard white chalk. The upper bed of brown chalk is 8 feet thick and contains

Act. granulatus and *Ostrea acutirostris;* the phosphatic matter is in the form of grains, some of which are casts of Foraminifera and others are phosphatised prisms of *Inoceramus* shell.

The chalk of Needham Market in Suffolk has also yielded *Act. quadratus* (*? granulatus*) and *Ostrea acutirostris*, but no higher chalk has yet been found in that county.

3. *Northern District*

Under this head we shall consider the chalk of Norfolk, Lincolnshire, and Yorkshire. In passing through Norfolk the Selbornian, the Lower Chalk, and the Middle Chalk all undergo great lithological change and pass into different types or facies which persist through Lincolnshire and Yorkshire. In Norfolk the strike is nearly from south to north and the dip is easterly, bringing in a great thickness of chalk towards Norwich and Cromer. In Lincolnshire and Yorkshire the prevalent strike is to the north-west and the dip north-east, except where it curves round the head of the syncline in Yorkshire.

Selbornian.—The Gault in its normal aspect, and including both Lower and Upper Gault, emerges from beneath the Fenland deposits near Stoke Ferry, and can be traced northwards to Grimston and Roydon near Kings Lynn.[16] At Stoke it is about 60 feet thick, but at Roydon it is barely 19 feet. In the railway cutting near Grimston there are marly clays with two beds of gray limestone and a bed of bright red marl more than a foot thick. The lowest limestone contains *Schl. rostrata*, *Hopl. lautus*, *Inoceramus sulcatus*, and *Inoc. concentricus*. At Dersingham there is only 7 feet of material to represent the Gault, the upper part calcareous, the lower a red and brown marl. Farther north it passes into the red limestone, which is generally called "red chalk" and is so strikingly exposed in the cliffs at Hunstanton. This red rock is only 3½ feet thick, and consists of three layers, each passing into the other. The lowest is sandy and of a deep brick-red colour full of *Actinocamax minimus* and *Terebratula biplicata;* the central part is a red nodular limestone with the same fossils and many others, including *Hoplites lautus*, *H. splendens*, *H. tuberculatus*, *Inoceramus sulcatus*, and *Inoc. concentricus*. The highest layer is a pale pink limestone with few fossils.

This "red rock" is continuous through Lincolnshire, where it is often 10 to 12 feet thick, but thins again to 4 or 5 near Caistor. In South Yorkshire the beds are about 7 feet thick, thinning to the north-east, till at Leavening and Wharram it is less than 2 feet, its base containing pebbles of quartz and ironstone. Eastward

however, it expands, and at Speeton it is represented by over 30 feet of material as below :—

		Feet.
Smooth and firm red marl	about	4
Red marl, enclosing lumps of harder and more calcareous material, with many fossils	,,	16
Tough red marly chalk in irregular beds	,,	10
Red, yellow, and green clays, shaly and gritty . . .	,,	1½

The lowest beds contain *Bel. minimus* and *Inoceramus sulcatus*, the higher hold *Terebratula biplicata*, *T. capillata*, *Kingena lima*, etc.

Lower Chalk.—As this is followed through Norfolk it becomes greatly reduced in thickness and at the same time harder and more purely calcareous, both these changes being evidently due to a diminution in the quantity of intermingled argillaceous matter. Thus at Heacham and Hunstanton the Lower Chalk has the following composition :—

		Feet.
Zone of *Offaster sphæricus*	5. Hard whitish chalk in rather thin beds. . .	35
	4. Rough dark gray chalk with a layer of green-coated nodules at the base (Totternhoe stone) . .	2
Zone of *Am. varians*	3. Hard creamy white chalk	13
	2 Hard gray rough and shelly chalk with a layer of green-coated nodules at the base . . .	4
	1. Hard white nodular limestone	1½
		55½

The hard shelly chalk (No. 2) is often called the "Inoceramus bed" because it is crowded with fragments of *Inoceramus* shells, probably of *Inoc. latus*. It also contains *Holaster subglobosus* and *Acanth. rotomagensis*, but the former ranges throughout the Lower Chalk, so that it is convenient to take another urchin to characterise the upper zone, and for this purpose *Offaster sphæricus*, common in the upper beds of Lincolnshire and Yorkshire, seems best.

It will be noticed that the Totternhoe stone is reduced to a thickness of only 2 feet, but it retains its characters and some of the fossils usually found in it ; moreover, it is traceable as a bed of about the same thickness all through Lincolnshire and Yorkshire.[17]

In Lincolnshire the only noticeable variations are (1) the red and pink coloration of two beds in the zone of *Offaster sphæricus* near Louth, (2) the reappearance of the Belemnite marl, which is absent near Hunstanton, but is often 2 feet thick in Lincolnshire, and is sometimes stained dark red or purple.

In Yorkshire the Lower Chalk maintains the Lincolnshire facies along the greater part of the escarpment, but at Speeton it shows some changes. The zone of *Am. varians* expands to 77 feet and the

lower part consists of nodular chalk in alternating pink and white bands. The zone of *Offaster sphæricus* is 46 feet thick, and the lowest bed is in places stained pink. At the top the Belemnite marls are well marked, enclosing a medial bed of hard smooth white chalk.

Middle Chalk.—In the north-west of Norfolk this division appears to be only about 100 feet thick. The Melbourn rock continues at the base of the zone of *Rhynchonella Cuvieri*, but the beds above are less nodular than they are farther south, and the zone of *Terebratulina lata* consists of hard white chalk with many layers of flints.

In Lincolnshire there is no definite Melbourn rock, and the zone of *Rhynch. Cuvieri* is reduced to a thickness of 10 or 15 feet, and consists of yellowish gray chalk full of fragments of *Inoceramus* shell and containing *Inoc. mytiloides*, *Rhynch. Cuvieri*, and *Terebratula semiglobosa*. At the top is a layer of gray shale, directly succeeded by a layer of white chalk traversed by a series of vertical joints, which break it up into small columnar pieces. The change is sudden, and the succeeding zone of *Ter. lata* consists of firm white chalk with frequent layers of gray flints. *Inoceramus Cuvieri* is the only common fossil, and the thickness of the zone may be 80 to 100 feet.

In South Yorkshire both zones are exposed in some large quarries near Hessle Station and have yielded a larger number of fossils, but little is known of the Middle Chalk in its course through Yorkshire except that the whole of it becomes very hard. In the cliffs near Speeton only the base of it can be reached.

Upper Chalk.—The only place in Norfolk where anything like the Chalk Rock has been found is to the west of Swaffham, but the zone of *Holaster planus* has been traced in North-west Norfolk by Bircham, Docking, and Titchwell. It has also been found in Lincolnshire near Louth and at several places in Yorkshire, but has not yet been mapped continuously. It comes into the cliffs on the north side of Flamborough Head, where it consists of very hard chalk, from which it is difficult to extract any fossils.

The zone of *Micraster cortestudinarium* has not been positively identified, but that of *M. coranguinum* occurs in all three counties with a nearly normal facies, consisting of white chalk with frequent layers of flint nodules and many continuous floors of flint. At Swaffham in Norfolk it has yielded *Cardiaster ananchytis*, *Infulaster excentricus*, *Micraster coranguinum*, and *Cidaris perornata*. Its thickness, however, is not yet known.

The higher zones have only been found in Norfolk and in Yorkshire. In Norfolk the *Marsupites* zone occurs at Houghton,

Walsingham, and Wells, and the zone of *Actinocamax quadratus* probably comes in to the westward, while near Norwich the zone of *Belemnitella mucronata* is found. The highest English chalk comes up on the coast near Cromer and Trimingham ; it consists of white chalk with very rough flints, and includes a layer of gray sandy chalk. The prevalent fossils in this chalk are *Bel. mucronata*, *Ostrea lunata*, *Terebratulina gracilis* (type), *T. gisei*, *Trigonosemus elegans*, *Galerites abbreviatus*, *Cardiaster ananchytis*, and a large number of Bryozoa. A boring at Norwich proved a thickness of 1152 feet of chalk, and probably about 1000 feet of this belongs to the Upper Chalk.

In Yorkshire the higher part of the chalk is well exposed in the cliffs of Flamborough Head, but it does not appear to reach quite to the zone of *Belemnitella mucronata*, although there is a measured thickness of 550 feet above the chalk with many flints.[18] This thickness consists mainly of flaggy white chalk with many thin seams of soft marl, and it is entirely destitute of flints. The lower part for about 280 feet above the highest bed of flints has not yielded *Marsupites* and but few other fossils ; in the next 117 feet *Marsupites* occurs, and is abundant in the upper 25 feet near Danes Dyke. The highest 155 feet of chalk between Danes Dyke and the termination of the cliffs near Sewerby is characterised by the abundance of fossil sponges. The most abundant species belong to the genera *Scytalia*, *Seliscothon*, *Siphonia*, *Stichophyma*, *Bolospongia*, *Phymatella*, and *Verruculina*. Other fossils found in this flintless chalk by Professor Barrois and Mr. J. W. Stather are (1) in the Marsupites zone, *Actinocamax granulatus*, *Act. verus*, *Inoceramus lingua*, *Offaster pilula*, *Infulaster rostratus* ; (2) in the higher zone, *Actinocamax quadratus* (or *granulatus*), *Inoceramus lingua*, *Rhynchonella limbata*, *Cardiaster ananchytis*, and *Infulaster excentricus*.

Mr. Lamplugh believes that another 100 feet of chalk comes in on the rising ground above Bridlington, and from a quarry in this Mr. Stather has obtained *Cardiaster ananchytis* and *Scaphites binodosus*.

4. *Ireland*

Upper Cretaceous rocks appear nearly everywhere round the edge of the great basaltic plateau of Antrim, Tyrone, and Londonderry, and we may therefore safely infer that they underlie the greater portion of it. It is also clear that they once extended much farther westward than the present edge of that plateau, as is proved by a small outlier near Draperstown. They usually rest on a planed down surface of Liassic or Triassic rocks, but some-

times overstep the limits of these, as in North-east Antrim, and rest upon the Palæozoic rocks (see Fig. 163).

A detailed description of these Irish Cretaceous rocks was given in 1865 by Professor Tate, and an attempt to correlate the divisions he proposed with the zones now recognised has recently been made by Dr. W. F. Hume, as shown in the following table :—[19]

Tate's Divisions.	Hume's Zones.	Feet.
5. White limestone	Zone of Belemnitella mucronata ,, Actinocamax quadratus	100
4. Chloritic Chalk	,, Actinocamax verus ,, Echinocorys gibbus	3 to 5
3. Chloritic Sands and sandstones	Inoceramus zone (Upper Chalk)	6 to 20
	Zone of Exogyra columba	4 to 15
2. Yellow sandstones =	,, Ostrea carinata	4 to 30
1. Glauconitic sands =	,, Exogyra conica	4 to 16

The glauconitic sands are regarded by Dr. Hume as in part equivalent to the Selbornian zone of *Am. rostratus*, but the occurrence of *Schl. varians*, *Pecten asper*, and an *Actinocamax* like *verus* (probably *lanceolatus*, Sow.) makes it difficult to accept this view. They are not likely to be older than the zone of *Pecten asper*. The yellow sandstones contain layers of chert, and their fauna is a curious mixture of Selbornian and Cenomanian forms, but as the beds are shallow-water deposits it is probable that Selbornian species here survived into Cenomanian time, and the occurrence of *Acanth. rotomagensis* marks them as equivalents of Lower Chalk.

The so-called Chloritic sands appear to include two deposits of very different age, separated by a break and unconformity. The lowest beds are calcareous glauconitic sandstones with *Exogyra columba*, *Pecten asper*, and *Trigonia crenulata*, and are evidently of late Cenomanian age. The higher beds are only found to the north of Belfast, and are seen at Woodburn, Island Magee, and Larne, and these sandstones yield *Echinocorys gibbus*, *Galerites conicus*, *Micraster Leskei*, *Rhynchonella limbata*, and *Terebratula carnea*, fossils which are sufficient to show that the beds belong to the Upper Chalk, but it is quite uncertain what zone they represent, for most of the species might belong to any zone from that of *Holaster planus* to that of *Marsupites*. But if the occurrence of *Micraster Leskei* is confirmed it points to the lowest zone.

The "Chloritic Chalk" is a pink limestone with grains of glauconite, and appears to be a condensed representative of a large part of the Upper Chalk of England, and was doubtless formed during conditions which were unfavourable to deposition, perhaps from the prevalence of strong currents. In the north of Antrim

this bed is represented by 5 feet of white limestone with flints, and yields Marsupite plates as well as *Actinocamax verus*.

The "white limestone" consists of hard white chalk with regular layers of flints, and may be regarded as equivalent to the zones of *Bel. mucronata* and *Ostrea lunata* (Norwich and Trimingham chalk). In the north of Antrim it has a band with *Actinocamax quadratus* at the base.

5. *Scotland*

Cretaceous rocks have only yet been discovered in one part of Scotland, namely, in the island of Mull and in the district of Morvern on the adjacent mainland; as in Ireland, they belong exclusively to the upper division of the system, and though they can be correlated generally with the Irish series, they exhibit a still more abnormal facies and a more decided approach to littoral conditions.

The characters and relations of the Cretaceous beds can be ascertained best in Morvern, along the shores of Loch Aline, and beneath the singular outlying masses of Beinn-y-Hun and Beinn-y-Hattan. The general succession here is given below:—[20]

	Feet.
4. Sandstones and white marls with plant remains (high Cretaceous or early Eocene)	20
3. White indurated chalk with bands of flints, *Belemnitella mucronata*, and fragments of *Inoceramus*; some beds of glauconitic chalk at the base	10
2. White sandstones without fossils, but containing a thin seam of coal	30 to 100
1. Glauconite sands, passing sometimes into dark green argillaceous sand, sometimes into calcareous sandstone; *Pecten asper*, *P. orbicularis*, *Exogyra conica*, but no Ammonites found	20 to 60

On comparing these beds with those of Antrim we may safely regard No. 1 as equivalent to Nos. 1 and 2 of the Irish sequence, but the absence of *Ammonites* and *Belemnites* in the Scotch beds is noteworthy as indicating the shallowness of the water in which they were deposited.

The overlying white sandstones (No. 2) would appear to be homotaxial with the zone of *Ostrea columba* in Ireland, whatever the precise age of that may be. Above it there is a palæontological break, though apparently no unconformity, and the hard white chalk corresponds closely to that of Ireland, except that there is no sign of the *Micraster* zone at its base.

6. *Northern France*

In France the Upper Cretaceous series exhibits two very different facies, that of the southern provinces being very different from that of the northern region, which is often called the Paris basin. The deposits found in the latter closely resemble those of England, and were evidently formed in the same sea, while those of Southern France belonged to a different marine province. Those of the Paris basin may first claim attention, and the following is a brief notice of them (see table on p. 421).

Albian.—The name of this stage is taken from the river Aube (or Alba), and in the department of that name it consists of the following members :—

	Feet.
Marls with *Am.* (*Schlænb.*) *rostratus* and *Ostrea vesiculosa* .	up to 200
Clays with *Am.* (*Hoplites*) *splendens* and *Am.* (*Hopl.*) *auritus*	,, 30
Clays with *Am.* (*Hoplites*) *interruptus* and *Am.* (*Douv.*) *mammillatus*	,, 60
Green sands without fossils	,, 30

Traced northward into the Meuse and Ardenne the basal sands contain *Am. mammillatus*, and pass into a siliceous rock (the "gaize de Draize"). The marls also pass into similar rock (the "gaize de l'Argonne"), which closely resembles our malmstone, and is undoubtedly of the same age.

These Albian deposits pass completely under the Paris basin. They have been reached by deep borings at Paris and Dieppe. They appear again in the anticlinal uplift of the Pay de Bray, and in diminished thickness they are found in the cliffs of Normandy. Near Cap la Hève the clays are about 10 feet, and the gaize with *Am.* (*Schlœnb.*) *rostratus* is about 26 feet thick.

Cenomanian.—The district where this stage was first established, that of Le Mans in the Sarthe, is unfortunately one where the beds have a sandy and shallow water facies, and are difficult to compare with the chalky facies which prevails in the eastern part of the Paris basin as it does in England. In Normandy, however, there is an intermediate type which affords valuable assistance in the correlation, and a fine section of it is visible in the cliffs near Cap la Hève :—

	Feet.
4. Grayish white chalk with gray flints	about 30
3. Gray chalk with cherts and phosphatic nodules . .	,, 10
2. Yellowish gray silty and glauconitic chalk with many layers of gray and black cherts, and some beds of bluish marly chalk near the bottom	,, 84
1. Bluish gray sandy glauconitic marl with black phosphatic nodules and many fossils	,, 6
	130

The basement bed contains *Stauronema Carteri* and *Schl. varians*, and is the equivalent of our Chloritic Marl. The beds above contain *Schl. varians*, *Acanth. Mantelli*, *Turrilites costatus*, *Pecten asper*, *P. Galliennei*, and *Holaster subglobosus*. Most of these also range into No. 3, but the whitish chalk above has few fossils.

Turonian.—The name of this stage is taken from Touraine, where it is divisible into two substages called (1) the Ligerian, and (2) the Angoumian.

Angoumian	Calcareous sands and sandy limestones with *Callianassa*, *Ostrea columba*, and *Acanthoceras Deveriæ*. Yellow sandy chalk with *Acanthoceras deverioides*.
Ligerian	Micaceous chalk with *Priono. Woolgari*, *Pachydiscus peramplus*, and *Am. Rochebrunei*, 60 to 1000 feet. Marly chalk with *Rhynch. Cuvieri*, *Inoceramus mytiloides*, and *Galerites subrotundus*, 30 feet.

Traced northward into Normandy these beds pass into pure chalk, and near Rouen the facies is the same as in England with a thickness of about 200 feet. At the base is hard nodular chalk like our Melbourn rock, succeeded by chalk with *Acanth. nodosoides*, *Prionotropis Woolgari*, and *Galerites subrotundus*, and this by soft chalk with *Terebratulina gracilis* (= *T. lata*), the higher parts of which contain *Holaster planus* and *Micraster Leskei*.

Senonian.—This name is taken from the district round Sens on the river Yonne, where the equivalent of our Upper Chalk is fully developed. French geologists, however, now divide it into two separate stages, a lower (Santonian or Emscherian) stage, which includes the zones of *Micraster cortestudinarium*, *M. coranguinum*, and *Marsupites*; and an upper (*Campanian*) stage, meaning the chalk of the Champagne country, which corresponds with the zones of *Actinocamax quadratus* and *Belemnitella mucronata*. A still higher zone is found near Ciply and Maestricht in Belgium and in a small isolated patch in the Cotentin (Normandy). At Ciply it includes the brown phosphatic chalk of that place and the lower part of the "tuffeau de Ciply," a yellowish white limestone, which is full of Bryozoa, and contains also *Belemnitella mucronata*, *Baculites Faujasi*, *Ostrea larva* (= *lunata*), *Thecidium papillatum*, and *Terebratula carnea*. At Maestricht hard limestones alternating with soft marls yield a similar fauna. These beds probably correspond with our Trimingham chalk.

Danian and Montian.—These names have been given to beds which are found here and there at the summit of the chalk in the Paris basin, in Belgium, and in Denmark.

In Belgium the higher part of the "tuffeau de Ciply" is referred to the Danian stage, for it yields many Gastropods but no

In the adjoining area near Mons there is a still
underlying Eocene beds and characterised by the
udoliva robusta, *Mitra Devalquei*, *Cerithium montense*,
Cidaris Tombecki, *Goniopygus minor*, and other

t chalk in the Paris basin consists of a yellow lime-
base, overlain by white marls and limestones. Gas-
e genera *Cerithium*, *Turritella*, *Mitra*, and *Pseudoliva*
nonest fossils, and the lacustrine genera *Viviparus* and
ccur, showing shallow water and estuarine conditions.

7. *Mediterranean Province*

uthern France and eastward through the Alpine region
atia the Upper Cretaceous series has a very different
The *Albian* of this region consists mainly of sands and
es, the *Cenomanian* of sandy limestones containing *Orbito-
tellina) concava* and many species of *Caprina*, *Caprotina* and
ala. The *Turonian* and *Santonian* are also represented by
ones, sandy limestones, and marls abounding with other
a of irregular Lamellibranchs, such as *Hippurites*, *Radiolites*,
Sphærulites, some of the beds being known as Hippurite
stones. These two divisions reach a thickness of 1500 feet
ome places. The higher stages are more local, but often
prise a great thickness of strata, thus in Provence they com-
e marly limestones of *Campanian* age, succeeded by a vast
up of freshwater deposits, which amount to a thickness of 2500
et and yield a large number of freshwater and terrestrial shells.
a character and thickness this group (the *Garumnien*) is analogous
o the English Wealden.

Geographical and Physical Conditions of Cretaceous Time

Lower Cretaceous Time.—We have seen (p. 391) that at the close of the Jurassic period the greater part of England presented the aspect of a fertile lowland district lying between two areas of higher ground, that on the west being separated into several hilly or mountainous districts by prolongations of the lowlands down the gap of the Bristol Channel and through the middle of Devon, that on the east presenting more gentle slopes, but probably rising into a high plateau towards Belgium. North-eastward the lowlands reached to the borders of a sea which might be truly called a "German Ocean," since it occupied not only the northern part of

what is now sometimes called by that name, but stretched far to the eastward through Germany itself. From the centre of England the broad plains of Jurassic deposits extended to the north-west over the space now occupied by the Irish Sea, and thence round the western borders of Scotland.

At the commencement of Cretaceous time deposits were being formed in two separate areas, marine deposits in Yorkshire and Lincolnshire, and freshwater deposits in the south of England. The Wealden Beds used to be regarded as the delta of a great river like that of the Nile or the Mississippi, but these rivers empty themselves into the sea, and we have no proof that the Wealden area lay at the head of a marine gulf. It is possible that such was its situation, but those who have specially studied the Wealden Beds consider it to be a purely lacustrine formation, and not so much the delta of one river as the result of contributions from several streams emptying themselves into a large lake.[21] In all probability the larger streams came from the west or north-west, and the exit of the lake was most probably at its south-eastern end, because there is little doubt that the Vectian sea gained access to the lake-basin from that direction.

With regard to the size and extent of the Wealden lake we can form a fairly correct estimate from the known extent of the beds themselves. We know that these extend from the centre of Dorset to the Boulonnais, a distance of nearly 200 miles. The rapid thinning out of the beds in Dorset shows that they did not reach much farther due west, but it is very likely that the lake was prolonged some distance to the south-west along the axis of the Channel-valley, and there can be little doubt that its waters covered a large part of the area which now lies between England and France. It is not assuming much, therefore, if we suppose that the Wealden Beds spread as far south of our present coast-line as they do to the north of that line. Now from the coast of Dorset they are known to reach inland for 30 miles, and in Hampshire a line joining the Vale of Wardour with the North Downs is 40 miles north of the south coast of the Isle of Wight. If, then, we assign the beds an original length of 200 miles and an average breadth of 70 miles, we obtain an area of about 14,000 square miles for their original superficial extent.

As already stated, the deposition of the Wealden Beds was contemporaneous with the formation of marine strata in France and Germany. The Germanic sea was extending itself westward, and a gulf connected with it lay over the eastern parts of Yorkshire and Lincolnshire. At the same time the Southern sea was gradually creeping north-westward up the valley of the river which

ran from the Wealden lake, and the distance between the lake and the sea was gradually lessened, till at length the last barrier was broken through and the Wealden lake became the Vectian gulf or estuary.

The change from the lacustrine shales of the Wealden to the marine clay of the Lower Vectian is sudden and complete ; there is no intercalation of estuarine deposits, and in this respect the change is like that from the Triassic marls to the Rhætic Beds ; but the actual conditions of the two cases were very different, the area of the Wealden lake was very much smaller, and its conversion into a gulf was not accompanied by the notable climatal change which took place in the earlier time, when the Triassic deserts were converted into fertile and forest-clad districts. The land of Vectian time was doubtless similar in climate and aspect to that of Wealden time, and the plants and creatures which inhabited the country were the direct descendants of those that lived in the Purbeck and Wealden periods.

For a certain time after the first invasion of the Wealden lake the land seems to have been nearly stationary, so that this basin was gradually silted up, and shallow-water conditions prevailed till further subsidence took place. Marine erosion, however, was active, and, aided by the subsidence, the sea spread farther and farther over the ground which separated the two gulfs, till at length the waves effected a junction across the lowest part of the intervening isthmus and invaded the lacustrine area, which seems at this time to have existed on the isthmus, and in which the Shotover sands were formed.

The extension of marine Vectian sands all across England, the frequent occurrence of pebble beds in them, and the current-bedding which they display, are facts which testify to their rapid accumulation under the influence of strong currents in a strait or channel connecting the northern and southern seas. This channel doubtless increased in width so soon as it was once established, but there is no evidence that the sea had encroached very far either on the eastern or western land before the formation of the Gault which overlaps the Vectian Sands in both directions.

Upper Cretaceous Time.—This is the record of a great and prolonged subsidence of the Franco-British region. It commenced with the submergence of the promontory which existed on the site of our eastern counties and the outspread of the Gault muds over the whole of South-eastern England ; at the same time the western shore of the Cretaceous sea was carried back to Devonshire, and doubtless also to the borders of Wales, though subsequent detrition has destroyed all evidence of the shore-line

north of Devon. From the present disposition of the Cretaceous strata, however, we can hardly avoid the conclusion that the whole of Central England was once more converted into a sea-bottom, on which marly clays and glauconitic sands were laid down, just as such deposits are now formed along the borders of our great oceans generally within depths of 500 fathoms.

The greatest thickness of Gault mud lies along a band which extends from north-west to south-east, from Bedfordshire and Buckinghamshire through Surrey and Sussex, and thence across the Channel to the departments of the Marne and Aube in France. Hence we may infer that the material was carried by a current which ran either from the north-west or from the south-east. If from the north-west it cannot have come out of the northern sea, for in that direction we find the Gault passing into the concentrated calcareous deposit of the Red Chalk ; it might have come from a river flowing down the Irish Sea and across Cheshire, but there is no confirmatory evidence of a great mud-bearing river coming from that direction ; hence we are driven to suppose that the material was brought down by rivers draining the Belgo-Germanic land, and that it was carried northward by a marine current setting from the south-east.

At the close of the Selbornian epoch the sea must have stretched to the borders of Dartmoor and across the greater part of Devon, leaving Exmoor as an island. The valley of the Bristol Channel was again a deep inlet penetrating far westward into the land, and thence the shore-line probably swept northward through Glamorgan, Monmouth, Hereford, and Shropshire into the Irish Sea, the plain of Cheshire forming a strait between the Cambro-Hibernian land and the Pennine promontory. From the eastern shore of this promontory the coast probably curved round so as to pass eastward across the North Sea, for it is most probable that there was at this time a continuous land connection between Scotland and Scandinavia.

The Lower Chalk is the result of a renewed movement of subsidence which carried the sea farther over the sinking lands, but more especially over the eastern land, for in Devon the representative of this stage is so thin and coarsely arenaceous that the depth of water in that area cannot have been much increased. Still we know from the overlap of the Cenomanian deposits in France that the sea did make further encroachments on the western land at this time, and it is also certain that the north-western gulf was more fully opened so that parts of Northern Ireland and the west of Scotland were submerged.

The Lower Chalk is thickest where it is most argillaceous or

marly, and the tract over which it has these characters corresponds roughly with that where the Gault is thickest but has a greater width, extending from Berkshire and Wiltshire over the whole of South-eastern England. Hence it is fairly certain that the current which carried the Gault mud still brought some of the same material into the Cenomanian sea. There is a rapid and notable diminution of argillaceous matter in the mass of the Lower Chalk as it is followed westward through Dorset, but it is remarkable that the argillaceous marl of the *Actinocamax plenus* beds was carried over the whole of Dorset and indicates a temporary increase in the strength of the eastern currents.

For the points of resemblance and difference between chalk and modern globigerina-ooze the reader is referred to the author's *Building of the British Isles*, and the *Geological Survey Memoir on the Chalk* (now in the press).

The character of the Middle Chalk has led all observers to infer that the depth of water was still greater during the time of its formation, and, as Dr. W. F. Hume remarks,[22] the maximum depression of the Turonian epoch probably coincided with the deposition of the middle part of the zone of *Terebratulina lata*. The chalk of this zone is throughout England of a very pure character, consisting of fine white chalk enclosing minute calcareous spheres, some scattered Foraminifera, and small particles of disintegrated shell, the insoluble matter being less than 2 per cent and appearing (when isolated) as a fine light brown clay. It is thickest in the south-east, round the Wealden area, but maintains a thickness of 80 to 100 feet through South Wiltshire, Dorset, and Devon without any material change of character, so that it must have extended far beyond the limits of the Lower Chalk.

The fauna of the Chalk Rock and other facts connected with zone of *Holaster planus* tend to show that the general subsidence was arrested during its formation, and even suggest that there was a reversed movement raising the sea-floor in England and in the north of France till the water was not deeper than it had been in the time of the Lower Chalk. The entire absence of anything comparable to the Middle Chalk or to the Chalk Rock in Ireland, and the characters of the white sandstones of Morvern (see p. 448), lend support to this view that the formation of the Upper Chalk was preceded by a movement of elevation.

The subsequent subsidence must have been more rapid and still more extensive than that which had previously taken place, but we still find deposition prevailing more in the east than the west, for the zones of *Micraster cortestudinarium*, *M. coranguinum*, and *Marsupites*, which in the south-east of England are about 450 feet

thick, are represented in Ireland by less than 30 feet; we may therefore conclude that the western region was never so deeply submerged as the eastern.

The subsidence of the southern and eastern areas probably reached its maximum during the formation of the zones of *Marsupites* and *Act. quadratus*, while during that of *Bel. mucronata* a reverse movement commenced, the effect of which is very apparent in Belgium and also in the characters of our Trimingham chalk. Towards the close of the Cretaceous period the upheaval seems to have been rapid, so that in Belgium we find shallow-water deposits with a fauna of a mixed Cretaceous and Eocene aspect.

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[19] "On the Cretaceous Strata of County Antrim," by W. F. Hume, *Quart. Journ. Geol. Soc.* vol. liii. p. 540 (1897).

[20] See Professor Judd in *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 728.

[21] See Topley in *Geology of the Weald*, p. 321, and Meyer, *Quart. Journ. Geol. Soc.* vol. xxviii. p. 247.

[22] The "Genesis of the Chalk," by W. F. Hume in *Proc. Geol. Assoc.* vol. xiii. p. 242 (1894).

CHAPTER XVI

TERTIARY OR CÆNOZOIC TIME

Palæogene System

As explained on p. 22, the Tertiary deposits are usually divided into five or six groups with a nomenclature based on the proportional number of species of Mollusca found in each group that have survived to exist at the present day. But these groups cannot be regarded as systems of the same palæontological value as those into which the Mesozoic and Palæozoic rocks have been divided. Only two such systems can be recognised in Cænozoic time, the *Eocene* and *Oligocene* divisions forming one system, the *Miocene*, *Pliocene*, and *Pleistocene* divisions forming a second.

For these two systems the German geologist Hoernes proposed the names *Palæogene* and *Neogene*, signifying the older and the newer kind of Tertiary life, and though not altogether satisfactory names, they have been widely adopted on the European continent. The name Eogene is used instead of Palæogene by some French geologists, but is too much like Eocene to be a convenient designation, and the names used in the first edition of this book, *Hantonian* and *Icenian*, must yield priority to those above mentioned.

In Britain there is a decided unconformity between the Cretaceous and Palæogene systems, a break which indicates a considerable lapse of time and a great change of physical and geographical conditions. We have seen that there are deposits in France and Belgium which partially bridge over this gap, and similar deposits may also have been formed in the British area, but if so they were destroyed before the deposition of our lowest Eocene strata. It is now certain that large tracts of the Upper Chalk have been removed from certain areas either before or during the formation of the earlier Eocenes, for we cannot doubt that the higher parts of the chalk were originally continuous

from Hampshire to Norfolk, yet they do not now exist under the London basin, and consequently the Upper Chalk, which in Sussex is at least 750 feet thick and in Norfolk is probably 1000 feet, has only a thickness of from 250 to 300 feet beneath the valley of the Thames. Moreover, where the Upper Chalk is thinnest, the London Eocenes are thickest, and there can be no doubt that these Eocenes were deposited in a broad and deep trough which had been excavated out of the Upper Chalk. The relation of this trough to the general surface of the chalk is indicated in the diagram, Fig. 151.

Life of the Palæogene Period

Eocene Life.—The difference between the fauna of the Chalk and that of the Eocene is very great indeed, for only one species, and that is a brachiopod (*Terebratulina striata*), seems to have survived the change of conditions in Britain, and not only so,

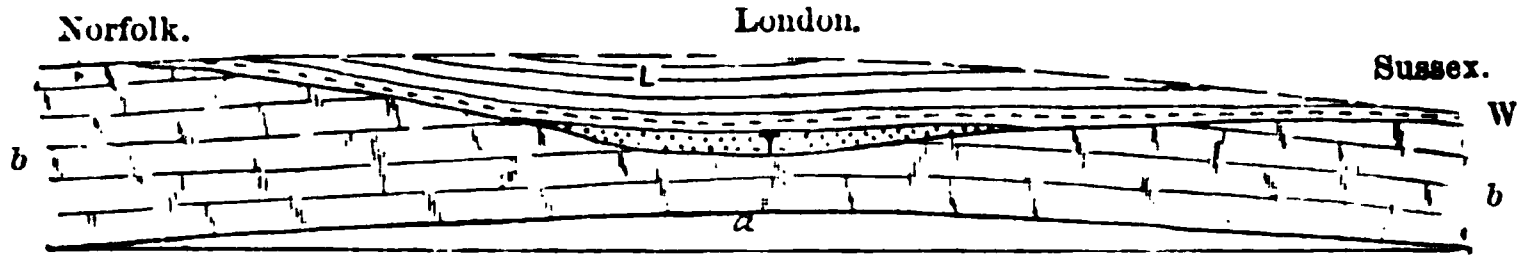

Fig. 151.—DIAGRAM TO ILLUSTRATE THE PRE-TERTIARY EROSION OF THE CHALK.

b, *b*. Upper Chalk. L. London Clay.
a, *a*. Base of Upper Chalk. W. Woolwich Beds.
T. Thanet Beds.

but the general aspect of the Eocene fauna is quite different from that of the Cretaceous. The great reptiles of the Secondary rocks have disappeared, and with them the numerous Cephalopods which are so characteristic of the Cretaceous system—the Ammonites, Turrilites, Baculites, Scaphites, Hamites, Belemnites, and many other genera; vanished also are the Hippurites, Radiolites, and Inocerami of the chalk, most of the Cretaceous Echinoderms, and all the deep-sea siliceous sponges (*Ventriculites*, *Cephalites*, *Ploco-spongia*, etc.).

The Eocene flora is marked by the incoming of Dicotyledons, especially of genera which now occur in tropical and subtropical regions. It should be mentioned, however, that many of the genera which now make their appearance in Britain occur in the higher Cretaceous deposits of the continent. The flora of the Woolwich and Reading Beds has a temperate aspect; it includes *Lygodium* (a fern), leaves like those of the poplar, plane, and hazel (*Populus*, *Platanus*, and *Corylus*), with some of *Laurus*, *Acacia*,

Grevillea and *Liriodendron*. The plants of the London Clay and Bagshot Sand, on the other hand, are those of a much warmer climate ; they include leaves and fruits of the conifers *Pinus* and *Sequoia*, with the palms *Elais*, *Musa*, *Callitris*, *Nipa*, *Sabal*, and *Areca ;* the Dicotyledons *Ficus*, *Aralia*, *Dryandra*, *Cassia*, and *Cæsalpina*, *Eucalyptus*, *Magnolia*, *Cactus*, and many kinds of *Leguminosæ*. In the Bournemouth Beds a still larger number occur, and form a different assemblage, but still one of sub-tropical aspect ; this includes ferns of the genera *Osmunda*, *Chrysodium*, *Pteris*, and *Gleichenia ;* the palms *Sabal*, *Iriartea*, *Flabellaria*, and *Phœnicites*, and the Dicotyledons *Dryandra*, *Eucalyptus*, *Palmacites* (a cactus), with fruits of *Hightia* and *Anona*.

Of invertebrate animals the following are some of the genera which now make their appearance in Britain, though some of the gastropods really date from the Upper Cretaceous beds of Europe :—

Protozoa.	Alveolina, Miliolina, Nummulites, Triloculina.
Actinozoa.	Balanophyllia, Dendrophyllia, Litharea, Madrepora, Oculina, Paracyathus, Solenastrea, Turbinolia.
Echinoderma.	Schizaster, Spatangus.
Crustacea.	Dromilites, Mithracia, Portunites, Xanthopsis.
Lamellibranchia.	Diplodonta, Glycimeris, Panopea, Potamomya, Sanguinolaria, Verticordia.
Gastropoda.	Ancillaria, Cancellaria, Cassis, Conus, Conorbis, Cypræa, Fasciolaria, Marginella, Oliva, Pyrula, Rostellaria, Tritonium, Trophon, Typhis, Xenophora.
Cephalopoda.	Aturia, Beloptera, Belosepia.

Vertebrate animals now become abundant, the four great classes of fish, birds, reptiles, and mammals being all well represented. The following are some of the genera found in the Eocene series of England and France :—

Fish.	Myliobatis, Ætobatis, Pristis ; Lepidosteus, Phyllodus ; Cœlopoma, Goniognathus, Dictyodus ; Eurygnathus, Percostoma, Sciænurus, and others.
Reptiles.	Gavialis (a Crocodile); Lacerta (a lizard); Palæophis (a sea-snake) ; Trionyx, Lytoloma, Argillochelys, (tortoises).
Aves.	Argillornis, Dasornis, Gastornis, Halcyornis, Eupterornis, Lithornis, Odontopteryx, all large birds. Odontopteryx had a large beak furnished with tooth-like processes.

Mammalia.—These deserve more special description. Marsupials of the genus *Didelphys* were common, and with these are carnivores (*Arctocyon* and *Palæonictis*) with strong marsupial affinities, but believed to be really placentals ; a little later appear other carnivora, *Amphicyon*, *Pterodon*, and *Proviverra*. The earliest known ungulate is *Coryphodon*, a primitive tapir from the Woolwich Beds and London Clay. A little later other genera appeared,

Lophiodon, *Palæotherium*, *Paloplotherium*, all related to tapirs and rhinoceroses, with *Hyracotherium*, which combined characters now found in the coney (*Hyrax*) and in the pigs. Other hog-like animals (*Hyopotamus*) appear in the Upper Eocene and become common in Oligocene time. There were also primitive hornless forms of deer or antelope named *Dichodon* and *Amphitragalus*. The rodents were represented by *Theridomys* and *Sciuroides*, and the Primates by the Lemuroid *Microchœrus*.

Oligocene Life.—The Oligocene flora does not differ in any great degree from that of Upper Eocene time; species of *Sequoia* are still abundant; palms are common; leaves of cinnamons, laurels, figs, camphor-trees, acacias, chestnuts, and other trees occur.

The invertebrate fauna is not large and is a direct development from the Eocene fauna, the genera being all survivors from the Eocene. Echinoderms were not abundant in our northern seas, but were common in the Mediterranean area, especially forms of the genera *Echinolampas*, *Echinocyamus*, and *Cœlopleurus*.

Of Vertebrates the Mammalia deserve special attention. A few genera such as *Palæotherium*, *Hyopotamus*, and *Dichodon* survive from the Eocene, but a large number of new genera make their appearance in the gypsum beds of Paris which correspond to our Headon Beds and form the Lower Oligocene of English and German geologists. Prominent among these is *Anoplotherium*, an ungulate of comprehensive type, combining characters now found in the tapir, pig, and horse. There were several species, the largest being about the size of a donkey, and having a long thick and strong tail which may have assisted him in swimming. *Anchitherium*, regarded as an ancestor of the horse, was no larger than a sheep, and had three hoofs on each foot. *Chœropotamus* is supposed to have been a river hog. *Xiphodon* and *Cainotherium* were hornless forms of antelopes, and *Hyænodon* one of the early carnivores resembling the marsupial wolf of Tasmania. In Southern France the jaw of a lemur (*Adapis*) has been found.

In higher Oligocene deposits corresponding to our Bembridge and Hampstead Beds other genera have been discovered, such as *Anthracotherium*, an ungulate remarkable for its strong canine teeth, and presenting several species which vary from the size of a hog to that of a hippopotamus. This beast and species of *Hyopotamus* are very abundant in the higher Oligocene. Other genera now appearing are *Dacrytherium*, *Dremotherium*, *Entelodon*, (all ruminants), the small carnivora *Pseudælurus*, *Plesictis*, and *Lutrictis*, and toward the close of the period the genus *Tapirus* with probably *Rhinoceros*. No Proboscidea have yet been found in beds of Oligocene age.

A. Eocene Series

Geographical Extent.—The present disposition of the Cretaceous outcrops in England and the restricted geographical extent of the Eocene deposits are both due to the disturbances and upheavals which took place in post-Oligocene times. These established a series of east and west flexures, and as the Palæogene deposits have been removed from the anticlinals, the parts which remain occupy two synclinal areas or basins which are known respectively as the London and the Hampshire Basins.

A glance at any geological map, or at the sketch-map, Fig. 157, will show the extent of the Palæogene deposits in these two areas. The London Basin extends from Hungerford in Berkshire to Reculvers in Kent, and its northern boundary passes from Reading through the counties of Buckingham, Hertford, and Essex to near Framlingham in Suffolk, where the influence of the syncline dies out and the boundary line then runs northward to the west of Yarmouth. Its length from Hungerford to Reculvers is about 120 miles, and its width from Sudbury to Canterbury is nearly 60 miles, but this is probably less than half its actual extent, the rest of the basin being concealed by the waters of the North Sea.

The Hampshire Basin is much smaller, and lies in a trough between the anticlinal axis of Winchester on the north, and the monoclinal of Purbeck and the Isle of Wight on the south, and its extreme width is, therefore, only 25 miles, while its length from Dorchester to near Worthing in Sussex is about 60 miles, with an outlier at Newhaven nearly 20 miles farther east.

There is evidence, however, of the original extension of the Eocene through Dorset and East Devon, and a small outlying tract of Eocene still exists near Bovey Tracey in Devon.

In Ireland freshwater beds of Eocene age are interstratified with the great sheets of basaltic lava which cover so large an area in Antrim and Derry. In Scotland a similar set of lavas, also with intercalated freshwater beds, attains a great thickness in the islands of the Inner Hebrides (Mull, Skye, etc.).

Subdivisions.—The labours of Prestwich, Whitaker, and others have made us well acquainted with the general succession of the Eocene series, but it must be remembered that up to the year 1880 the Eocene of British geologists included what is now known as the Oligocene, and it was not till 1888 that the Oligocene series was adopted in the publications of the Geological Survey. The following are the subdivisions of the Eocene series now recognised in the London and Hampshire Basins, and they can be grouped

into Lower and Upper Eocene, but the creation of a Middle Eocene is quite unnecessary.

	London Basin.	Feet.	Hampshire Basin (Isle of Wight).	Feet.
Upper	? Wanting.		Barton Sands	120 to 220
	Bracklesham Sands	about 200	Barton Clay	224 to 142
	Bracklesham Clays	,, 60	Bracklesham and Bournemouth Beds	555 to 583
Lower	Bagshot Beds	,, 150	Bagshot Beds	243 to 98
	London Clay	,, 400	London Clay	230 to 320
	Woolwich and Reading Beds	,, 80	Reading Beds	80 to 160
	Thanet Beds	,, 80		1450 to 1520
		About 970		

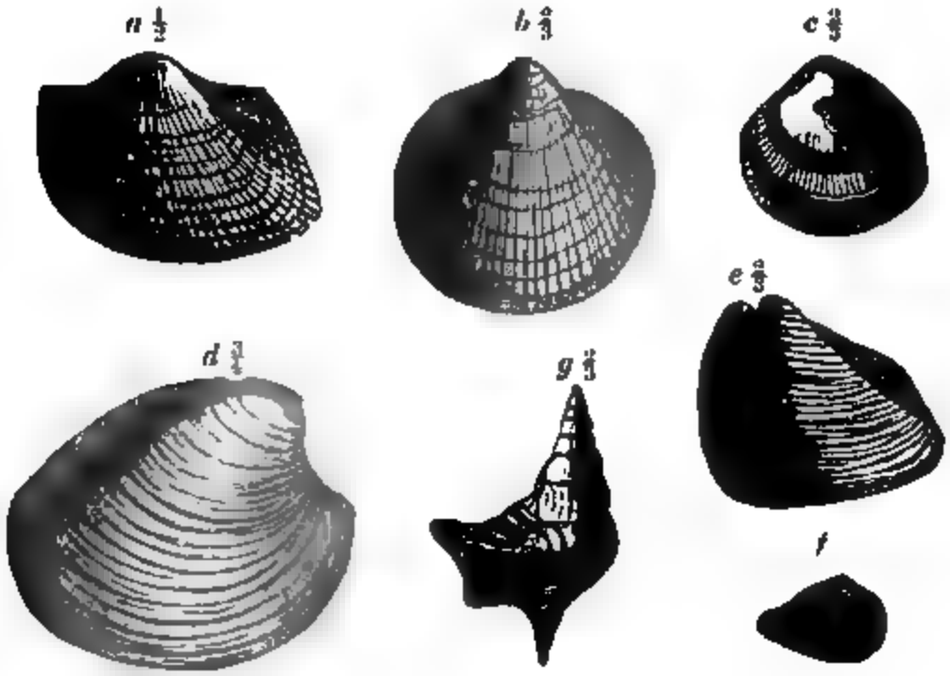

Fig. 152. FOSSILS OF THE THANET BEDS.

a. Cucullæa decussata.
b. Pectunculus terebratularis.
c. Protocardium Laytoni.
d. Cyprina planata.
e. Pholadomya cuneata.
f. Corbula regulbiensis.
g. Aporrhais Sowerbyi.

Characteristic Fossils.—The following are some of the commoner and most characteristic species of invertebrates found in the marine and estuarine deposits of the Eocene series :—

Fossils of the Thanet Beds

Lamellibranchia. Protocardium Laytoni, Corbula regulbiensis, Cucullæa decussata, Pectunculus terebratularis, Cyprina planata, Pholadomya cuneata.

Gastropoda. Aporrhais Sowerbyi, Trophon subnodosus, Scalaria Bowerbanki.

Fossils of the Woolwich and Reading Beds

Lamellibranchia. Cyrena cuneiformis, C. tellinella, Cyprina Morrisi, Ostrea bellovacina, O. tenera, Unio subparallela.

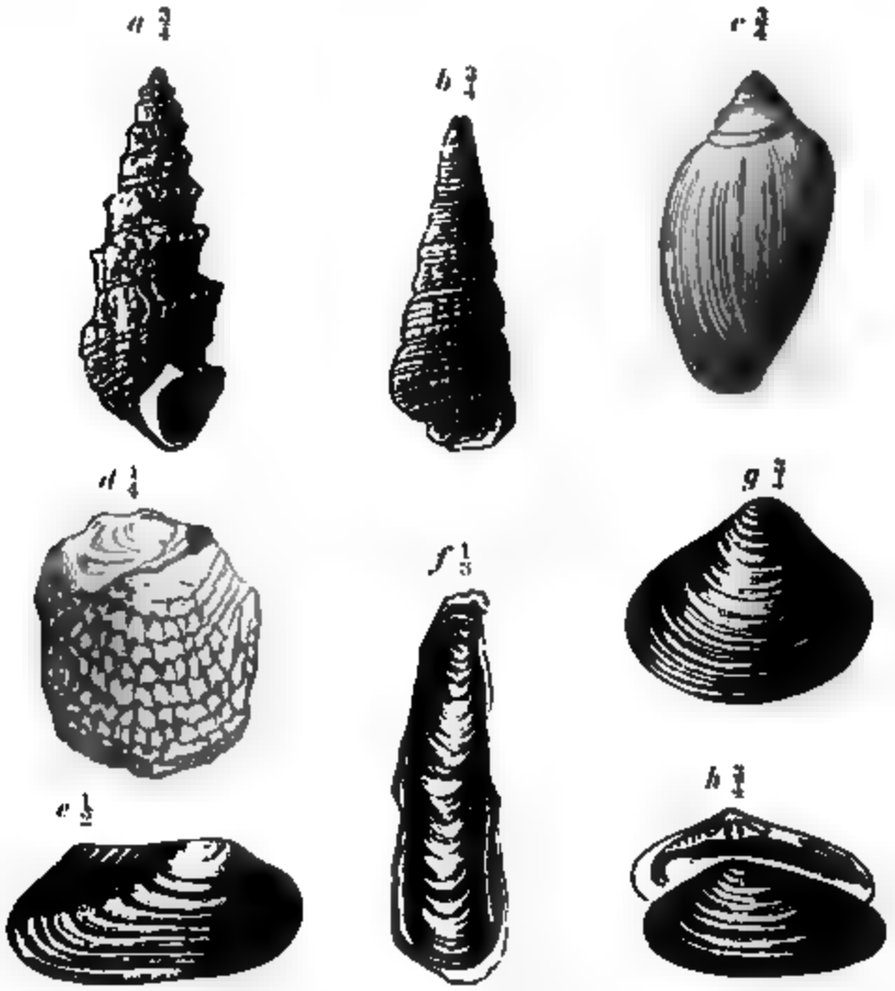

Fig. 153.—FOSSILS OF THE WOOLWICH BEDS.

a. Melania inquinata.
b. Potamides funatus.
c. Pitharella Rickmani.
d. Ostrea bellovacina.
e. Unio subparallela
f. Ostrea tenera.
g. Cyrena cordata.
h. Cyrena tellinella.

Gastropoda. Potamides funatus, Calyptrea aperta (= trochiformis), Melanopsis buccinoidea, Melania inquinata, Neritina globulus, Pitharella Rickmani.

Fossils of the London Clay

Annelida. Ditrupa plana, Vermicularia bognoriensis.
Crustacea. Hoploparia Belli, Xanthopsis Leachi.

Brachiopoda. Lingula tenuis, Terebratulina striatula.
Lamellibranchia. Cardita Brongniarti, Axinus angulatus, Pholadomya margaritacea, Pinna affinis, Modiola elegans, Panopæa intermedia, Pectunculus decussatus.

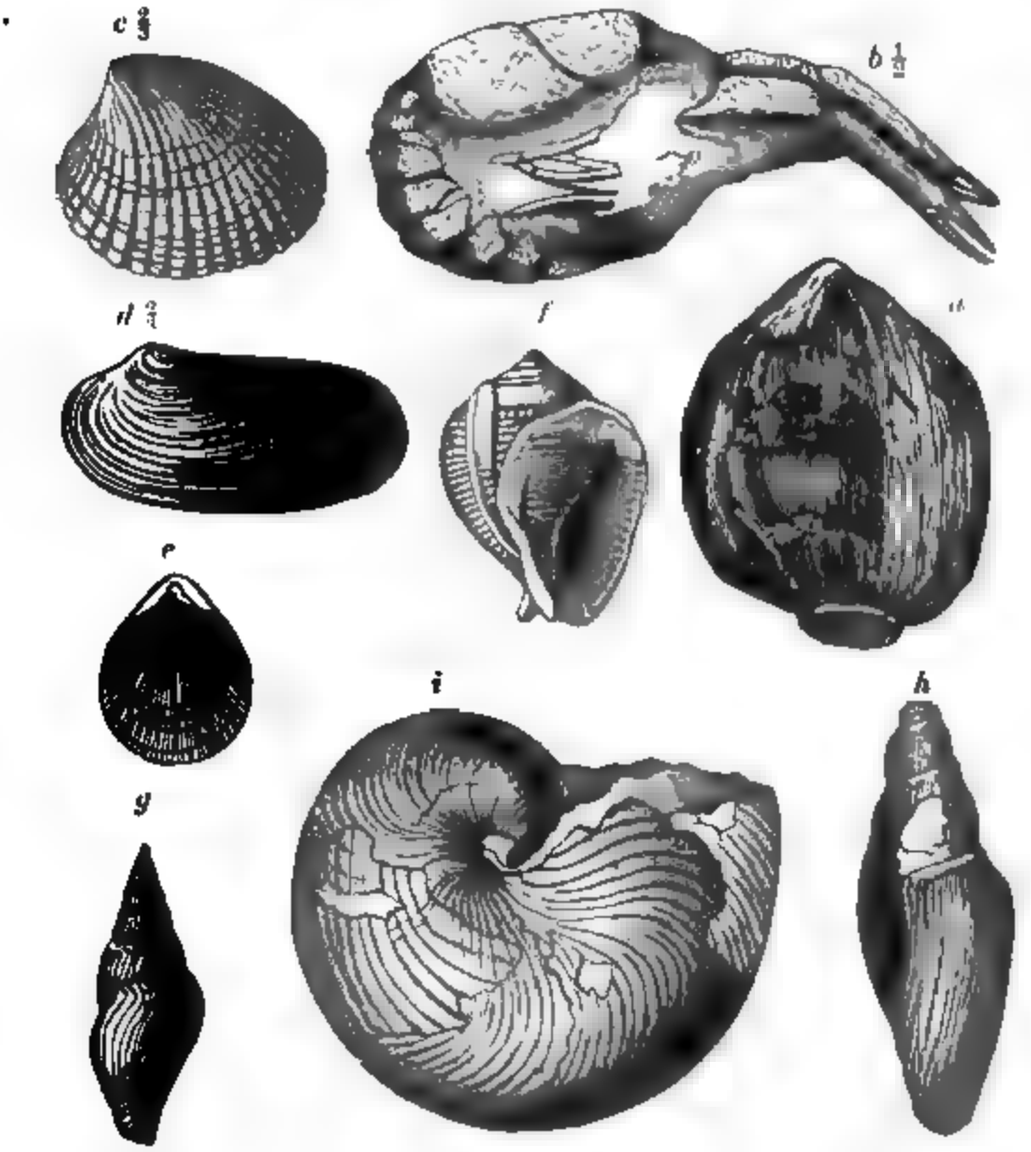

Fig. 154.—FOSSILS OF THE LONDON CLAY.

a. Nipa elliptica (fruit).
b. Hoploparia Belli.
c. Cardita Brongniarti.
d. Panopea intermedia.
e. Terebratulina striatula.
f. Cassis striata.
g. Pleurotoma prisca.
h. Voluta Wetherelli.
i. Nautilus imperialis.

Gastropoda. Aporrhais Sowerbyi, Cassis striata, Xenophora extensa, Pleurotoma prisca, Pyrula Smithi, Voluta Wetherelli.
Cephalopoda. Nautilus imperialis, N. regalis, Aturia ziczac.

Fossils of the Bracklesham Beds

Protozoa. Nummulites lævigatus, N. variolarius.
Actinozoa. Litharæa Websteri.

Lamellibranchia. Arca biangula, Pecten corneus, Cardita planicosta, Solen obliquus, Sanguinolaria Hollowaysi, Chama squamosa, Pectunculus pulvinatus.

Gastropoda. Fusus longævus, F. pyrus (range into Barton beds), Cypræa Coombii, Cerithium giganteum, Turritella imbricataria, T. sulcifera, Conus deperditus, Pleurotoma attenuata, Voluta nodosa, V. spinosa.

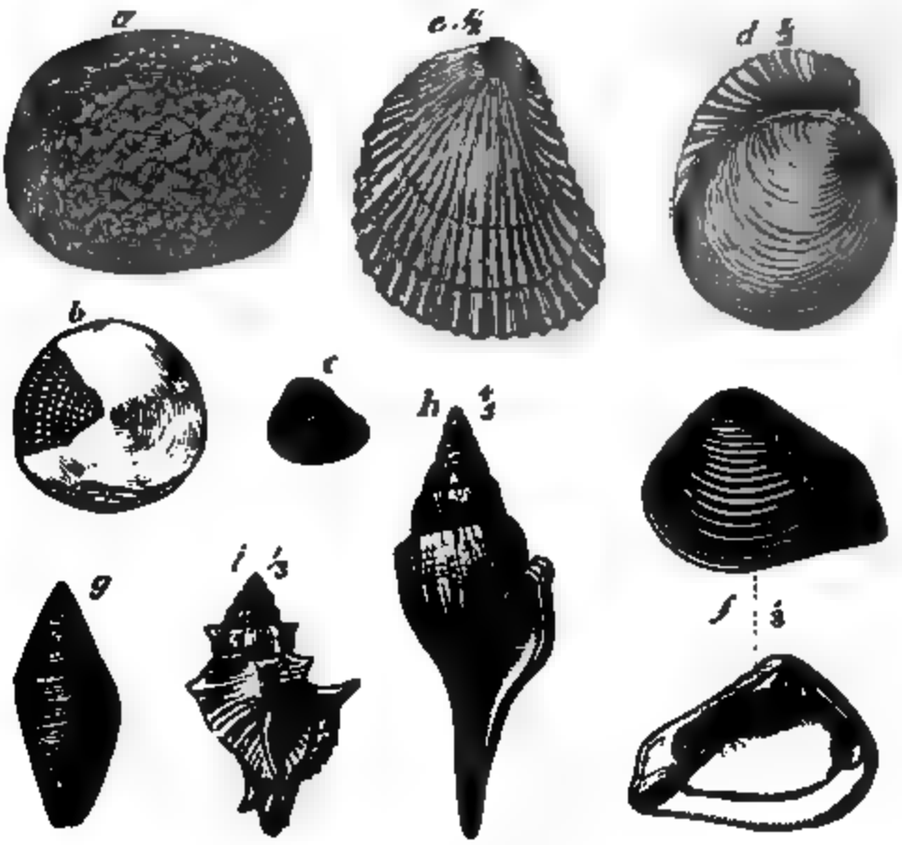

Fig. 155.—FOSSILS FROM THE BRACKLESHAM AND BARTON BEDS.

a. Litharea Websteri.
b. Nummulites lævigatus.
c. Ostrea flabellula.
d. Chama squamosa.
e. Corbula pisum.
f. Crassatella sulcata.
g. Conus dormitor
h. Fusus longævus
i. Murex asper.

Fossils of the Barton Beds

Protozoa. Nummulites elegans.

Echinoderma. Schizaster d'Urbani.

Lamellibranchs. Cardita sulcata, Crassatella sulcata, Cardium porulosum, Corbula pisum, Pecten reconditus, Pectunculus deletus, Sanguinolaria compressa.

Gastropoda. Rostellaria ampla, Rimella rimosa, Conus (Conorbis) dormitor, Murex asper, Typhis pungens, Voluta athleta, V. luctatrix, Xenophora agglutinans, Oliva Branderi.

Stratigraphy

1. *The London Basin*

The Lower Eocene is more fully developed in the London basin than in Hampshire and includes the lowest division (Thanet beds), which does not occur in Hampshire (see table on p. 463). On the other hand, the Upper Eocene is thin and poorly developed in this district, and occupies but a small area.

The Thanet Beds, as their name implies, are well developed

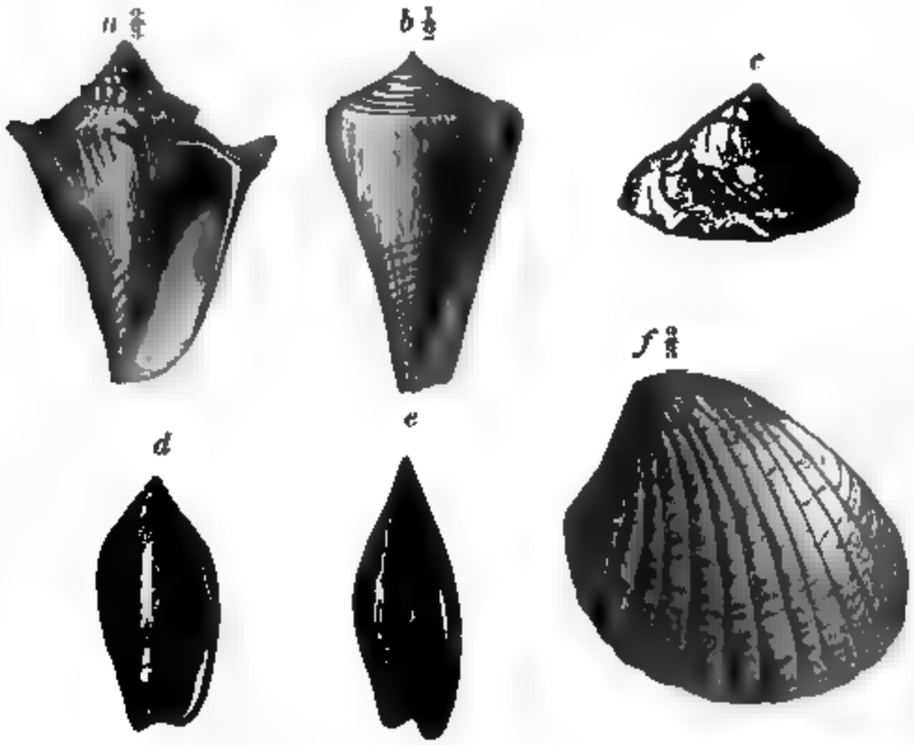

Fig. 156.—FOSSILS OF THE BRACKLESHAM AND BARTON BEDS.

a. Voluta athleta.
b. Conus deperditus.
c. Xenophora agglutinans.
d. Oliva Branderi.
e. Ancilla buccinoides.
f. Cardita planicosta.

in the Isle of Thanet. They consist mainly of pale-coloured sands, the lowest part being always argillaceous and full of dark green glauconitic grains, while at the base, and resting on the chalk, there is invariably a layer of *unworn* green-coated flints. These flints show no signs of attrition, and are believed to have been derived directly from the underlying chalk, not by mechanical erosion, but by chemical solution, through the agency of carbonated water percolating through the sands and dissolving the subjacent chalk, but leaving the insoluble flints behind, so that a layer of these nodules has gradually accumulated at the base of the sand,

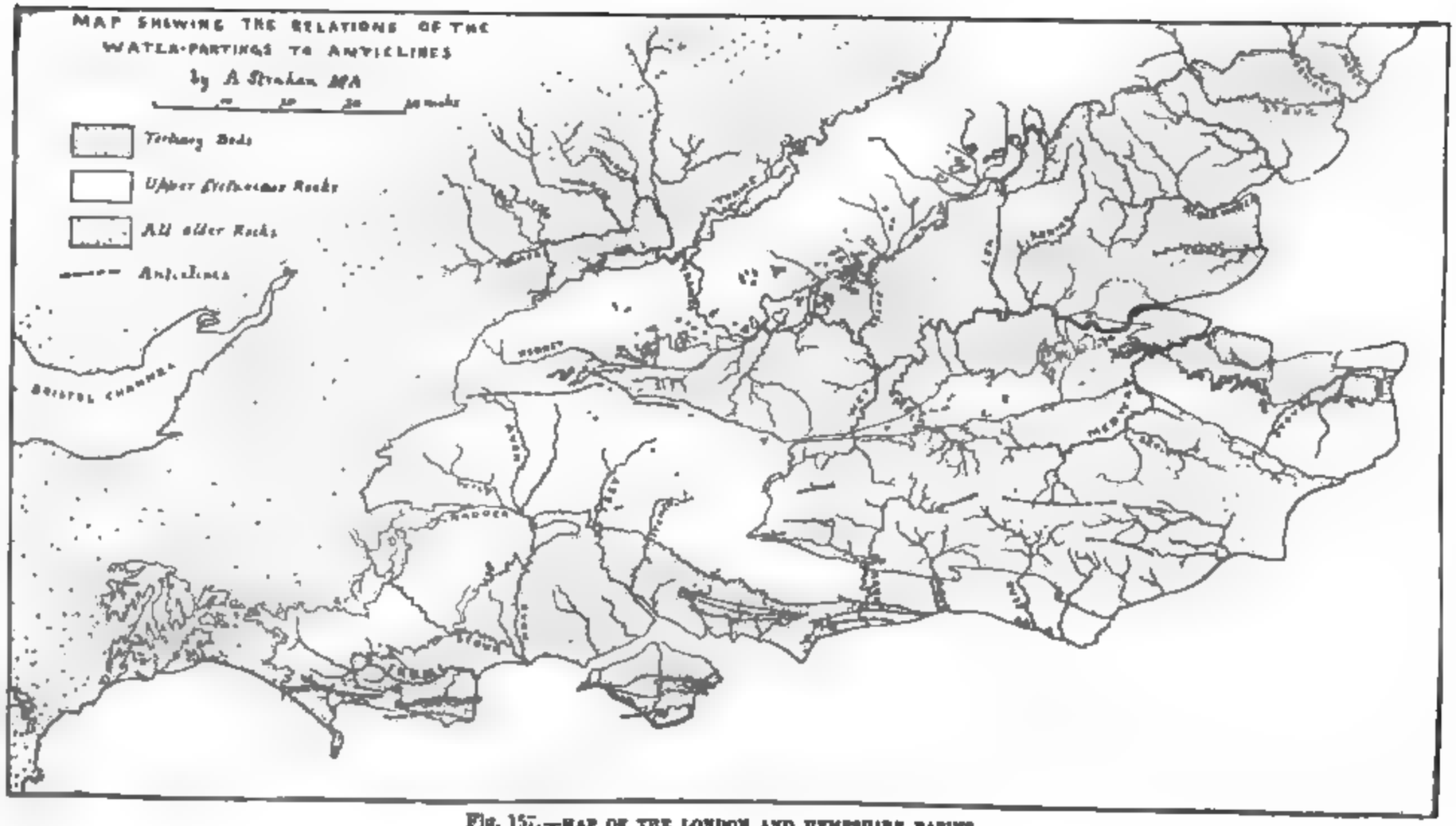

Fig. 157.—MAP OF THE LONDON AND HYMPSHIRE BASINS.

but was not there when the sands were originally deposited. This supposition is confirmed by the fact that no fossils occur in this basement bed, whereas if the flints had ever lain on a sea-bottom small oysters, serpulæ, etc., would certainly have fixed themselves on to such favourable surfaces for attachment.

In East Kent the greater part of this stage consists of greenish sandy marl (50 or 60 feet), overlain by sharp greenish gray sand (30 to 40 feet), and both beds contain many fossils (see p. 463); the best exposure is in the cliffs of Pegwell Bay near Ramsgate, and this is illustrated in Fig. 158. It is also seen at Reculvers on the north coast of Kent. Westward the sandy marl passes into fine soft pale green or buff sand (argillaceous at the base), while the upper sands appear to thin out, so that in the west of Kent the whole is not more than 50 feet thick; this type of the Thanet Beds is well exposed in the pits near Woolwich and Charlton, but contains no fossils. Thence the outcrop runs by Crayford and Croydon to Epsom, where the sands are only 15 feet thick, thinning out entirely near Ashstead.[1]

The Thanet Beds thin northward as well as westward, for though well-sections at Chelmsford and Braintree show them to be about 30 feet thick, at their outcrop near Sudbury they are only 16 feet, and they thin out rapidly eastward and also to the west near Gestingthorpe in Essex.

The Woolwich, Reading, and Oldhaven Beds.—These form a much more variable group, and exhibit three different facies as they are traced from east to west:—(1) the marine type, consisting of gray sands with marine shells, is only found in East Kent; (2) the estuarine or *Woolwich* type occurs in West Kent and East Surrey, and consists of sands, clays, and pebble beds, with estuarine and freshwater shells; (3) the *Reading* type of the western and northern tracts consists of unfossiliferous variegated plastic clays and bright-coloured sands.

Overlying the marine and estuarine beds of the Woolwich group in Kent and Surrey are pebbly sands and pebble beds, from 10 to 50 feet thick, which are termed the *Oldhaven or Blackheath beds* by Mr. Whitaker, and are grouped by him as a third division of the Lower London Tertiaries. Their stratigraphical extent, however, is not great, and their palæontological importance is small, so that they hardly seem entitled to rank as a primary division. Prestwich was of opinion that they should be classed either with the Woolwich Beds or with the London Clay, and since at Charlton and Sundridge they contain many estuarine shells of Woolwich species their fauna seems to connect them rather with the lower beds than with the London Clay.

Fig. 158. SECTION ALONG THE CLIFF ALONG THE NORTH SIDE OF PEGWELL BAY, KENT (by H. Burrows and R. Holland).

A. Loam (Pleistocene).
B. Yellow and buff sands.
C. Gray and buff sands.
D. Dark greenish sandy marl.
E. Dark gray shaly marl.
F. Gray green and yellow sandy marl.
G. Layer of green-coated flints.
H. Upper Chalk.

N.B.—The Thanet beds comprise G to B inclusive.

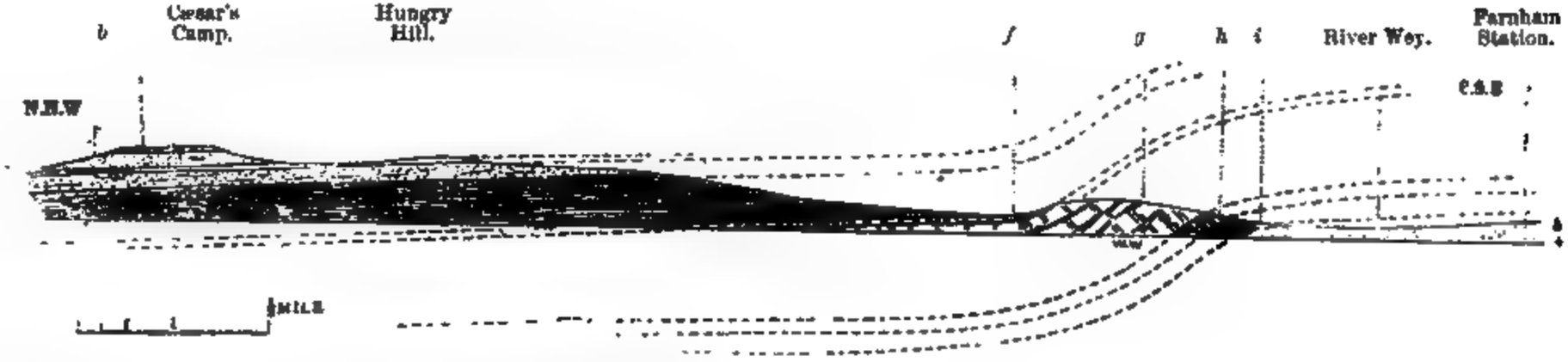

Fig. 159.—SECTION FROM NEAR ALDERSHOT TO FARNHAM IN SURREY (by W. Whitaker).

a. Gravel.
b. Barton beds.
c. Bracklesham beds.
d. Bagshot sands.
e. London clay.
f. Reading beds.
g Chalk.
h. Greensand } Selbornian.
i. Gault }
k. Vectian.
x, x. Sea-level.

The coast near Reculvers in Kent furnishes a good section of the marine type of this group, as follows :—

	Feet.
Oldhaven Beds.—Gray and buff sands, hardened in places into a ferruginous sandstone ; a layer of pebbles at base . . .	20
Woolwich Beds.—Pale gray sand with sharks' teeth, *Corbula regulbiensis*, *Protocardium Laytoni*, *Cyprina Morrisi*, etc. . .	25

Near Milton estuarine beds come in near the middle of the Woolwich beds, and at Upnor on the Medway the general succession is the following :—

		Feet.
Oldhaven Beds.—Sands with marine shells and a layer of pebbles		8 to 15
Woolwich Beds	Light-coloured sands with clayey seams .	up to 15
	Clays with estuarine shells	,, 6
	Sands, chiefly of a pale green colour . .	,, 30
	Layer of black flint pebbles	,, 1
		About 60

At and near Lewisham the Oldhaven Beds are very thin, but the Woolwich Beds are 50 feet thick and have sandy pebble beds in the lower part (20 feet thick). At Woolwich, on the other hand, there are only a few pebbles at the base and a great development of pebble beds at the top ; these are known as the Blackheath Beds, and rest on an eroded surface of the Upper Woolwich sands.

The Blackheath Pebble Beds do not extend west of Croydon, and are not found along the northern edge of the London basin. The pebbles composing them are all well-worn and rounded flints without any subangular pebbles such as occur on our shingle beaches ; hence Mr. Whitaker concludes that they were not laid down in beaches, but were deposited by strong currents at some little distance from the shore, and his view is confirmed by the frequency of current bedding.

Beds of mottled plastic clay begin to appear in West Kent near the base, and these increase westward through Surrey, the shell-bearing beds gradually dying out, till in Hampshire and Berkshire they consist entirely of mottled clays, in tints of red, yellow, gray, purple, and green, associated with beds of red, yellow, and white sand. These are known as the Reading Beds, and marine fossils only occur in the basement bed, the only fossils in the mottled clays being leaves of plants. Near Reading the following succession is found :—

	Feet.
Mottled clays	40 to 50
Yellow and white sands	20 to 30
Bottom-bed with marine fossils	5 to 8

Beds of the same (Reading) type range along the northern lip of the basin through Herts and Essex, but include some pebble beds which are occasionally concreted into the kind of conglomerate known as "plum-pudding stone." Near Sudbury the Reading beds are thin, but extend eastward as far as the valley of the Deben north of Woodbridge, whence their boundary line probably turns northward, but the outcrop is concealed beneath the Pliocene deposits.

The London Clay forms the third division of the London Tertiaries, and occupies broad areas both on the north and south side of the Thames Valley. It is of much more uniform composition than the lower group, the mass of it consisting of stiff bluish clay with layers of septarian nodules. Its thickness near London is between 400 and 500 feet, but it thins gradually westward to about 270 at Wokingham, 50 near Newbury and Hungerford, and only 15 in the outlier of Great Bedwin in Wiltshire, but this rapid thinning may be only apparent, and due in reality to a replacement by sand of the Bagshot type.

The basement bed is of a different character to the rest, consisting of brown, gray, or greenish sand and sandy clay, in which are scattered many rolled flint pebbles; these pebbles are always black, and sometimes have the remarkable peculiarity of falling into fragments when tapped by a hammer, for though to the eye they seem compact, they appear to be really traversed by a multitude of invisible cracks. This basement bed is generally from 6 to 12 feet thick, and it often contains fossils, of which the chief are *Aporrhais Sowerbyi*, *Calyptrea aperta* (= *trochiformis*), *Cytherea obliqua*, *Panopæa intermedia*, *Pectunculus brevirostris*, and *Ditrupa plana*.

The surface colour of the overlying mass of clay is generally brown, but this is due to the oxidation of the iron it contains by exposure to the weather; its normal tint in deep wells and borings is a bluish gray or slate colour.

Fossils are not common throughout the London Clay, but sometimes occur in great profusion, especially where beds of sandy clay occur. The cliffs of the Isle of Sheppey are noted for the fossils they yield; plant-remains are there especially abundant, and bones of birds, turtles, and snakes have also been found (see *ante*, p. 460).

Bagshot Sands.—These beds occupy a much smaller space than the London Clay because they have been removed from the greater part of its surface by subsequent detrition and erosion, but there is good reason to believe that they were not only coextensive with the London Clay but spread beyond its original borders. The chief remaining tract of Bagshot Sand is an area about 24 miles in

length with a breadth of about 10 or 12 miles, and occupying parts of Berkshire, Hampshire, and Surrey. Aldershot, Farnborough, Bagshot, Wokingham, Ascot, and Cobham all lie within this area. Westward there are several outlying tracts, some large and some small; and north of the Thames in Middlesex are three small outliers capping Harrow, Hampstead, and Highgate Hills (see Fig. 160). Other patches occur in Essex, the principal one near Brentwood.

The extreme thickness of these sands in the Bagshot and Farnborough country is from 130 to 150 feet, the London clay in the same district being about 330 feet. Westward at Ramsdell, in the outlier between Basingstoke and the valley of the Kennet, there is a bed of brown clay very like London clay and 30 feet thick in the lower part of the Bagshot sand, or it may be said that there is a bed of sand in the upper part of the London clay, suggesting the view that there is a replacement of that clay by sand in the west of the London basin.

The Bracklesham Beds (formerly called Middle Bagshot Beds) consist of brown laminated clays at the base, overlain by dark green clayey sand from 12 to 20 feet thick, and succeeded by a variable set of greenish sands with bands of clay, the total thickness varying from 40 to 80 feet. These beds have yielded a few fossils, *Fusus longævus*, *Turritella sulcifera*, *Cardita planicosta*, *Pecten corneus*, *Ostrea flabellula*, *Corbula striata*, *Nummulites lævigatus*, and many fish teeth, *Lamna obliqua*, *Carcharodon auriculatus*, etc.

Above the clays is a mass of sands formerly called the Upper Bagshot Sand, but now referred to the Bracklesham group. At the base is a layer of small flint pebbles, and the fine yellow and white sands which succeed are the highest Eocene beds that occur in the London basin. Their thickness appears to be over 200 feet, for in a boring at the Albert Asylum, Bagshot, their depth proved to be 226 feet.[2] These sands are irregularly bedded, and contain in the upper part blocks of white saccharoid sandstone, which, when weathered out, are known as "gray-wethers"; these masses are sometimes 10 to 14 feet long, and 3 or 4 deep, and they often enclose flint pebbles. Organic remains are rare, but here and there are casts of shells, and about forty-eight species were obtained by Mr. Monckton from the Tunnel Hill cutting near Pirbright on the South-Western Railway. Among these the commonest were *Rimella rimosa*, *Natica patula*, *Turritella imbricataria*, *Ostrea flabellula*, *Pecten reconditus*, *Cardita sulcata*, *Lucina mitis*, *Tellina scalaroides*, and *Corbula pisum*, a fauna which Mr. Monckton regards as indicative of a Barton age for these sands, but most of the species occur also in Bracklesham beds.

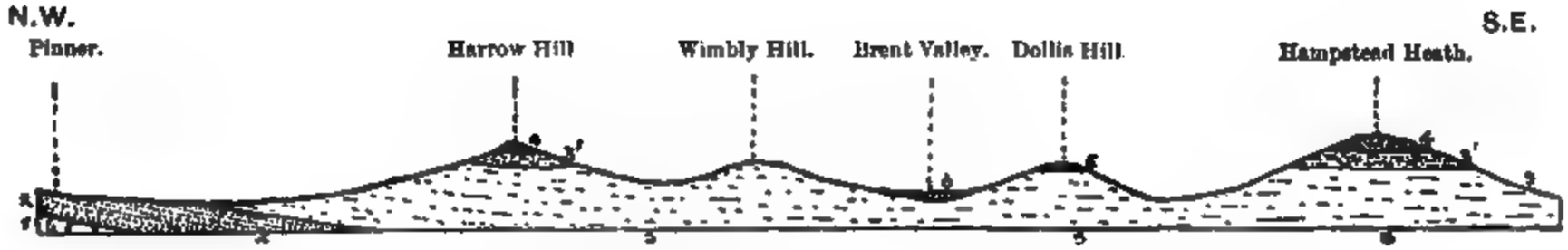

Fig. 160.—SECTION FROM PINNER TO HAMPSTEAD (by J. L. Lobley). Distance 12 miles.

6. River gravel.
5. Plateau gravels.
4. Bagshot sands.
3'. Upper sandy London clay.
3. London clay.
2. Woolwich and Reading beds.
1. Upper Chalk.

Fig. 161.—SECTION ACROSS THE WESTERN END OF THE ISLE OF WIGHT (by H. W. Bristow).

Oligocene
11. Pleistocene gravel.
10. Bembridge limestone.
9. Lower Bembridge beds.
8. Headon beds.

Upper Eocene
7. Barton sand.
6. Barton clay.
5. Bracklesham beds.

Lower Eocene
4. Bagshot sands.
3. London clay.
2. Reading beds.
1. Upper Chalk.

2. *Hampshire Basin*

The most complete sections of the Eocene series in the basin are found in Alum and Whitecliff Bays at the eastern and western ends of the Isle of Wight (see map, Fig. 146), but the central and upper portions of the series, being more fossiliferous at certain places on the opposite coast of Hampshire, take their names from those places, *e.g.* Bournemouth, Bracklesham, and Barton Beds.

In the Isle of Wight the beds are thrown up on end into a nearly vertical position (see Fig. 161), and the thicknesses of the several divisions can thus be easily measured.

Reading Beds.—This group is the lowest member of the series, for the Thanet Beds have not been found in any part of the Hampshire Basin. The Reading Beds consist almost entirely of bright red and white mottled clays with several layers of brown sand, one of these being at the base and resting on the chalk. No fossils except fragments of plants have yet been found in these clays, and they do not therefore seem to be of marine origin. Their thickness in Whitecliff Bay is 163 feet, at Alum Bay 84 feet, and they are still from 70 to 80 feet thick in Dorset near Bere Regis. Near Dorchester they include beds of sand and of subangular gravel consisting of Chalk flints and Greensand chert.

London Clay.—With the exception of an outlier at Newhaven, the most easterly exposure of this division in this area is at Bognor in Sussex, where beds of clay and calcareous sandstone, highly fossiliferous, are exposed on the shore, and are supposed to belong to the lower part of the London Clay.

Borings at Portsmouth Dockyard below the summit of the formation proved a thickness of 290 feet, and exposures made in extending that dockyard from 1868 to 1870 were described by Mr. Meyer,[3] who found the clay divisible into three parts, each commencing with a layer of pebbles and passing upward from stiff clays into sandy clays. The lowest zone is about 100 feet thick, the middle zone has a thickness of 134 feet, and the sandy beds in the upper part of this yielded many fossils. The uppermost zone consists mainly of clays containing *Cyprina planata*, *Pholadomya margaritacea*, *Rostellaria lucida*, and other species.

In the Isle of Wight the London clay is about 320 feet thick at Whitecliff Bay, but only 230 at Alum Bay.[4] In Whitecliff Bay the basement pebble bed is 2 inches thick, and about 35 feet higher there is a zone of *Panopæa intermedia* and *Pholadomya margaritacea*, and at 120 a band of large oysters. According to Mr. Meyer this oyster bed is about the same horizon as the lower pebble bed at Portsmouth. The beds above it consist mainly of

stiff brown clays with *Panopæa intermedia*, *Cyprina planata*, and *Cytherea tenuistriata*, and *Pinna affinis*. At 262 feet from the base there is a layer of black flint pebbles, and above this are sandy and laminated clays.

In Dorset the London Clay consists chiefly of brown sandy loam with seams of sandy ironstone and a bed of flint pebbles at the base. Its thickness in the Purbeck district is from 70 to 80 feet, but it thins westward, and is finally overlapped by the Bagshot beds near Dorchester.

Bagshot Beds.—These are bright yellow and white sands with bands of gray laminated sand and clay and (in the upper part) layers of white pipe-clay, which contain leaves and stalks of plants belonging to the genera *Aralia*, *Cæsalpinia*, *Comptonia*, *Dryandra*, *Ficus*, *Laurus*, *Quercus*, and other Dicotyledons. Ferns are rare in the Isle of Wight, but *Chrysodium lauzeanum* abounds at Studland in Dorset. This flora indicates a warmer climate than that of the Reading beds.

There is much difference of opinion as to the thickness assignable to these beds in the Alum Bay section; the Geological Survey classes all the sands and clays which do not yield marine fossils as Lower Bagshot, and these amount to 662 feet. Mr. J. S. Gardner,[5] however, has shown that the special Bagshot flora does not occur above the pipe-clays, and that the higher beds at Bournemouth contain a very different flora. He also thought that the lower part of these sands replaced the upper part of the London Clay, but if the latter is restricted to 233 feet, the Bagshot sands will have a thickness of 243 feet at Alum Bay, but decrease eastward till they are only 98 feet in Whitecliff Bay.

At Studland and Corfe in Dorset the Bagshot beds have the same facies, but westward they pass into coarse subangular gravels, which near Dorchester overlap both London clay and Reading beds so as to rest directly on the chalk. These gravels contain pebbles of Chalk flint, Greensand chert, and Purbeck marble, with many of quartz and of Palæozoic rocks probably derived from the Permian breccias of Devonshire. Still farther west they overstep the chalk and rest on the Selbornian sands.

Bracklesham Beds.—These beds received their name from Bracklesham Bay in Sussex, where they contain marine shells throughout their whole extent along the shore, but there are no cliffs in which they can be measured.

The section in Whitecliff Bay exhibits the same marine type, and has been described in detail by the Rev. O. Fisher,[6] who divides the group into the four portions given below. More recently, however, Mr. H. Keeping has been able to fix the limit

between the Bracklesham and Barton beds more exactly, and finds it to be about 70 feet lower than where Mr. Fisher placed it. Making this alteration, the thicknesses of the several parts are as follows :—

		Feet.
A.	Green and blue clays with a bed of sand about 52 feet from the base, *Nummulites variolarius*, *Pecten corneus*, *Corbula pisum*, *Pleurotoma plebeia*, etc.	182
B.	Yellow sands and sandy clays, *Num. variolarius* . . .	27
C.	Sandy clays and green sands, *Num. lævigatus*, *Sanguinolaria Hollowaysi*, *Voluta spinosa*, etc.	123
D.	Laminated clays and green sands with a bed of pebbles at the base, *Num. lævigatus* and a few other fossils	251
		583

It will be noticed that C and D form a zone of *Nummulites lævigatus*, while A and B are characterised by *Num. variolarius*.

On reaching Alum Bay we find that the greater part of this group is represented by unfossiliferous sands and clays, probably estuarine beds, and that marine shells are only found in the uppermost 157 feet, which answer to Mr. Fisher's group A. The lower beds were formerly relegated to the Lower Bagshot, but their true position has been determined by Mr. Gardner, who has compared them bed by bed with those of the opposite cliffs of Hampshire.[7] The following are the divisions according to Mr. Gardner's reading, the letters and figures indicating their correlation with the Whitecliff and Bournemouth sections respectively :—

			Feet
A.	6.	Greenish sandy clays with pebbles at base	45
	5.	Yellow and white sands	41
	4.	Bluish and brown clays with lignite bands . . .	71
B.	3.	Bright-coloured sands	147
C.	2.	Dark sands and clays with lignite	98
D.	1.	Dark laminated clays and variegated sands . . .	153
			555

The succession of the Bournemouth and Boscombe beds has been carefully worked out by Mr. Gardner, who gives it as follows :—

		Feet.
6.	Dark sandy clays with pebbles at base	14
5.	Highcliff sands, white and without fossils	31
4.	Hengistbury clays with septaria containing sharks' teeth . .	57
3.	Boscombe sands of various colours containing pebbles . .	140
2.	Bournemouth marine beds with plants and marine shells . .	50
1.	Bournemouth freshwater beds with plant-remains only . .	?400
		About 590

The Freshwater beds consist largely of sand with occasional

bands of clay in which leaves are abundant, especially leaves of *Salix* (willow), *Iriartea* (a palm), *Sequoia Couttsiæ*, *Araucaria*, *Eucalyptus*, and the ferns *Osmunda*, *Polypodium*, and *Acrostichum*.

The Marine beds (2) are similar, but among the plant-remains are *Palmacites* (a cactus), *Dryandra*, and fruits of the *Nipa* palm.

West of Pool nothing more is seen of this group till we reach the neighbourhood of Newton Abbot in Devonshire, and though this can hardly be called a part of the Hampshire basin, and is in fact a small basin in itself, it will be convenient to describe it here, because the beds are similar to those of Bournemouth and the flora is so much the same, "not only in species but in their mode of grouping and preservation, that were specimens mixed, they could not be reseparated" (J. S. Gardner).

These Bovey Beds rest directly on Carboniferous and Devonian rocks in a basin-shaped fashion, the basement beds being pebbly gravels consisting, like those of the Bagshot Beds, of stones derived from the surrounding Palæozoic rocks as well as from the Greensand and Chalk; these are covered by a succession of gray and white sands and clays with frequent layers of lignite. The total thickness of these beds is unknown, but is believed to be from 300 to 400 feet. Their surface forms a tract of low-lying heath-covered ground extending from Bovey Tracey on the north-west to Kingskerswell on the south-east, a distance of about 9 miles. Plant-remains are abundant in some of the beds, and include *Sequoia Couttsiæ* (a conifer resembling the great *Sequoia gigantea* of California), cinnamons, evergreen-oaks, figs, vines, and laurels; the commonest fern is *Osmunda lignitæ*, which is indistinguishable from *Osmunda bromeliæfolia* of the Philippine Islands.

Barton Beds.—The most careful study of these beds in recent years is the memoir by Messrs. Gardner, Keeping, and Monckton,[8] on which the following account is based. They divide the stage into three parts, which they call Lower, Middle, and Upper Barton, but the Geological Survey divide it into the Barton Clay and the Barton Sands, which is in some ways a more convenient division.

According to the three authors above mentioned the thicknesses of their divisions at the three principal sections are as follows:—

	Barton.	Alum Bay.	Whitecliff.
Barton Sands or Upper Barton . .	90	114	221 feet.
Barton Clay { Middle Barton . . .	53	167	92 ,,
Barton Clay { Lower Barton . . .	49	57	55 ,,
	192	338	368 ,,

The Lower Barton has at its base a thin zone of green sandy clay in which *Nummulites elegans* (var. *prestwichiana*) is common, and serves to define the Barton from the underlying Bracklesham Beds. Above are gray clays and sands characterised by *Voluta athleta*, *Cassis ambigua*, *Rimella bartonensis*, *Cominella canaliculata*, and *Schizaster d'Urbani*.

The Middle Barton, or Barton Clay proper, consists mainly of gray and brown clays with bands of septaria, and its prevalent fossils are *Voluta luctatrix*, *V. ambigua*, *Rostellaria ampla*, *Fusus longævus*, *Murex minax*, and *Crassatella sulcata*. At Alum Bay there is a remarkable increase in the thickness of this group, and the upper 70 feet consist of yellowish sandy clays with many small Mollusca, but no such beds are seen at Whitecliff.

The Barton Sands at Barton present the following succession:—

	Feet.
4. White and yellow sands with *Cerithium plcurotomoides*, *C. concavum*, *Oliva Branderi*, and *Melania hordeacea* . . .	20
3. Dark gray sandy clay with *Oliva Branderi* and other shells .	26
2. White sand without fossils	25
1. Bluish gray clayey sand (the *Chama* bed) with *Chama squamosa*, *Terebratula bisinuata*, *Terebellum sopitum*, *Voluta costata*, *V. humerosa*, and *Conus scabriculus*	18

At Alum Bay the *Chama* bed is rarely exposed, and the higher beds are represented by a mass of yellow and white sand from 90 to 100 feet thick, which has been largely dug for glass-making. These sands are sometimes called the Headon Hill sands, and at the east end of the island they thicken to 206 feet, and the Chama bed is seen below them with a thickness of 15 feet.

3. *Ireland*

Basaltic Series.—This series has been mentioned in previous chapters as forming an elevated plateau in the north-east of Ulster, a plateau which has steep escarpments on every side except toward Lough Neagh, and is mainly composed of enormous lava-flows, but intercalated with the lowest of these are deposits of detrital origin.

The basement bed of the series is generally a conglomerate containing flints derived from the chalk, and resting on a very uneven surface of the underlying rocks (Chalk, Trias, etc., see Fig. 163). Above this there is a variable set of ochreous tuffs, iron ores, laterites, clays, and lignites, which are sometimes only a few feet thick, but sometimes swell out to 30 or 40 feet, and are in some places intercalated with sheets of dolerite, which still further increase the thickness of these basal beds. Over them, however, are piled immense and extensive sheets of basalt

Fig. 162.—DIAGRAMMATIC VIEW OF ARDTUN HEAD (by J. S. Gardner). Distance about 1½ mile.

a, a. Intrusive sill of basalt.
b, b. Basaltic lava-flows.
c, c. Interbedded fluviatile deposits.
d. Supposed dyke.

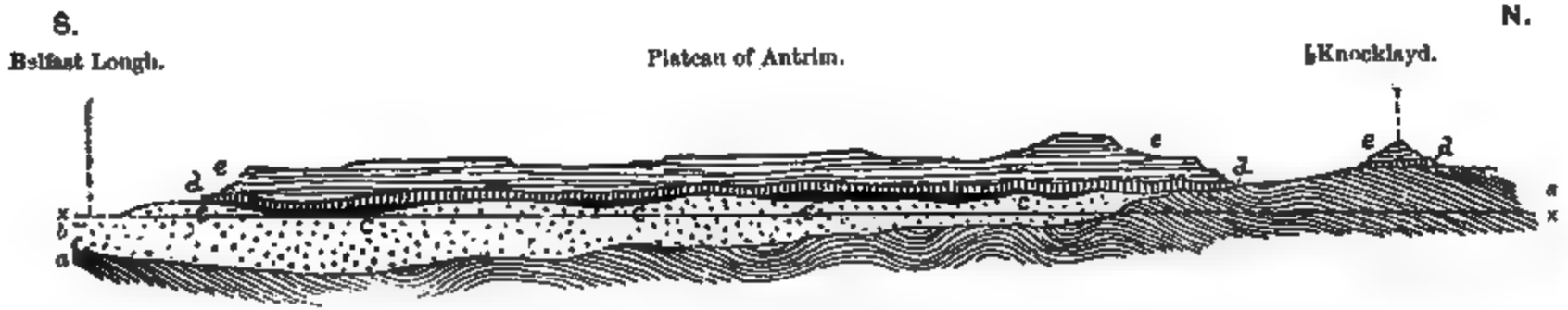

Fig. 163.—DIAGRAMMATIC SECTION ACROSS THE PLATEAU OF ANTRIM. Distance about 40 miles.

e. Eocene lava-flows (basalts).
d. Cretaceous series (chalk, etc.).
c. Patches of Lias and Rhætic beds.
b. Triassic marls and sandstones.
a. Palæozoic rocks.
x, x. Sea-level.

and dolerite, which at Sleamish have a minimum thickness of 1200 feet. The well-known columnar basalt at the Giant's Causeway is one of these sheets and overlies a bed of bole or laterite, while the basal conglomerate, here of considerable thickness, and not associated with clays or iron ores, can be seen beneath massive dolerites near Dunluce Castle.

At Glenarm and near Antrim there are thick deposits of iron ore, the lower bed being a compact ferruginous earth known as lithomarge, which is sometimes 40 feet thick, and is overlain by pisolitic ore, and these occur some 600 feet from the base, and 400 feet from the top of the basaltic formation. At Glenarm they are associated with sandy clays and pebble beds, which enclose a seam containing well-preserved leaves and plant-remains. Among these *Daphnogene Kanei*, *Sequoia Coutssiæ*, *Macclintockia Lyelli*, and leaves of *Platanus*, *Quercus*, and *Rhamnus* have been identified by Baily. Mr. J. S. Gardner considers the flora to be of early Eocene age, not Miocene as previously supposed.

Lough Neagh Beds.—Round the shores of this lake are deposits which may be of Eocene age, but of rather later date. The relation of these beds to the neighbouring basalts has not yet been definitely ascertained, and the evidence for regarding them as Pliocene or Pleistocene appears to be insufficient. According to Mr. Gardner[9] they resemble the Bovey Beds, "being a mass of alternating white, brown, greenish blue, and red plastic clays, white and gray sand with irregular beds of lignite," and the flora supports this view of their age. They have been pierced near Anaghmore to a depth of 260 feet without reaching the base.

4. *Scotland*

The basaltic plateau of Ulster is only a portion of a very extensive tract of similar materials which has been largely broken up and destroyed, but must have originally stretched northward to the west coast of Scotland, where other large remnants of it are found in the Isle of Mull, Eigg, Rum, Skye, and Raasey. In the present connection the most important Scottish locality is the promontory of Ardtun Head in the south-western part of Mull. Here beds of gravel sand and shaly clay are intercalated between two great sheets of basalt and have yielded many plant-remains. The beds were first investigated by the late Duke of Argyll, but more recently by Mr. J. S. Gardner,[10] from whose account the following is taken, together with the illustrative section, Fig. 162.

The sedimentary rocks appear along the seaward face of the

headland for a distance of rather more than a mile, and the succession seen in one of the quarries is as follows :—

	Feet.
Rudely columnar basalt	10
Bedded sandstone	8
Indurated gravel of flints and lava-fragments	7
Indurated dark coloured mud with ferns	1
Black crumbly shale full of leaves	2½
Hard gravelly sand resting on basalt	2

At other points there are several beds of clay or shale which contain leaves, and similar beds also occur near Carsaig. The plant-remains include a fern (*Onoclea hebridica*) and an *Equisetum*, many Gymnosperms, such as *Ginkgo*, *Podocarpus*, *Taxus*, and *Sequoia*. Dicotyledons are abundant and include leaves of *Platanus hebridicus*, *Populus arctica*, *Cornus hyperborea*, *Bœhmeria antiqua*, and leaves like those of *Corylus*, *Laurus*, and *Rhamnus*. Mr. Gardner considered the flora to be more like a late Cretaceous than a Tertiary one, but accepting its probable connection with the Antrim area, was inclined to regard it as of very early Eocene age, and not newer than the time of the Thanet Beds.

The Region of Volcanic Activity

The northern parts of the British Isles were a scene of remarkable volcanic activity throughout a large portion, if not the whole, of Eocene time, and evidences of this activity are found not only in the vast lava-flows above mentioned but in lava-filled fissures of great length. The region over which such phenomena have been found embraces the north of England, the north of Ireland, and the whole of Southern and Western Scotland, a total area of about 40,000 square miles. Its history has been written by Sir Archibald Geikie, from whose account the following epitome has been condensed.[11]

This great development of volcanic action seems to have coincided with a general elevation of the region above indicated, as if it had been pushed upward by the accumulation of a vast sea of liquid lava beneath it. Whether as cause or coincidence, it seems certain that great horizontal tension arose which started a series of fissures, these running generally from north-west to south-east, and sometimes extending for 50, 60, or even 100 miles. Into these fissures welled up the liquid rock which has consolidated into basalt, and where they reached the surface the lava welled out in vast streams like those of modern Iceland, forming the great basalt plateaux of Antrim and the west of Scotland.

This process of dyke-making and the outpouring of lava-floods

was repeated again and again, till in the great vale or plain which bordered the west of Scotland the lavas accumulated to a depth of several thousand feet. In some places 3000 feet of them still remain, and we know not how great a thickness has been removed. Here and there they filled up and obliterated river-channels like those in the island of Mull.

After the building up of these plateaux another episode took place. Large bodies of a basic magma were pushed into and through the plateau basalts and consolidated into huge domes of gabbro, troctolite, and other such coarse-grained rocks, but whether they ever extruded matter at the surface cannot be known, because the summits of the bosses are removed.

The next phase was the protrusion of material from a different magma, which has consolidated into acid rocks of various kinds, from glassy obsidians and rhyolites to granophyres and a rock of granitic character. These now form conical hills which resemble in some respects the trachytic hills of Auvergne.

The last phase was a second formation of fissures, producing another system of basic dykes which traverse all the previously formed rocks, cutting not only the older dykes but the great masses of gabbro and granophyre. Whether they poured lava to the surface is not known, and whether the formation was the final episode is not quite certain, for there is also a series of acid dykes which also traverse all the older volcanics and do not appear to be cut by the later basic dykes. The age of these later basic and acid dykes is also uncertain ; they may be Oligocene, or even Miocene ; but whenever vulcanism did cease the whole region began to sink down again, and at the present time great parts lie below the sea.

Continental Equivalents

The Eocene area of Belgium may be regarded as a continuation of the London Basin, for the two are doubtless in actual connection beneath the North Sea. Again, the deposits of the Paris Basin present such a great resemblance to those of the Hampshire Basin that they can be correlated without much difficulty, and were doubtless formed within the same area of deposition. In the south of France however and in the south of Europe generally, the Eocene series exhibits a very different facies, consisting largely of hard foraminiferal limestones full of *Nummulites*, *Operculina*, and *Alveolina*, and generally known as Nummulite limestones ; with these are calcareous sandstones containing many large shells, reef-building corals, and echinoderms of many species.

The accompanying table shows the Eocene succession in the

CORRELATION TABLE OF ENGLISH, FRENCH, AND BELGIAN EOCENE

	English Divisions.	French Stages.	Paris Basin.	Belgium.	Aquitaine.
Upper (Parisian).	Barton Sands. Barton Clay.	Bartonian.	Sables de Monceux, Calcaire de St. Ouen, Sables de Beauchamp. 60 to 120 feet.	Wemmélian (sands), 130 to 160 feet.	Freshwater limestone of Plassac, Green clay of Blaye with *Num. variolaria*.
	Bracklesham and Bournemouth Beds.	Lutétian.	Calcaire Grossier: Cuillasses, Cerithium beds, Miliola beds, Nummulite beds. 40 to 150 feet.	Lackinian, Bruxellian, (sands and sandstones), 200 feet.	Limestones with *Orbitolites complanata*, Clays with *Num. perforata*, Limestones with *Num. biarritzensis*.
Lower (Bessonian).	Bagshot Sands. London Clay.	Yprésian.	Sables de Cuise, Sables d'Aizy, 100 to 160 feet.	Ypresian: Sables de Mons, 100 to 200 feet, Argile de Flandres, 300 feet.	Limestones with *Operculina Heberti*.
	Woolwich and Reading Beds.	Sparnacian.	Sables de Sinceny, Lignites de Boissonnais, Argile plastique, 50 to 160 feet.	Sands and marls (Upper Landenian), 30 to 60 feet.	Limestones with *Alveolina* in the Pyrenees.
	Thanet Beds.	Thanetian.	Sables de Bracheux, Sables de St. Omer, 40 to 60 feet.	Lower Landenian and Heersian, 30 to 100 feet.	

Paris basin, in Belgium, and in Aquitaine, and the French divisions or stages as correlated with the English. It is based on that given by Professor de Lapparent (1900),[12] who divides the portion which corresponds with our Eocene series into five stages, and it will be convenient to adopt this grouping in giving a brief account of the deposits in these regions. The name of *Thanetian* is derived from our Isle of Thanet, *Sparnacian* from Eparnay (Sparnacum), *Yprèsian* from Yprès in Belgium, *Lutetian* from the Roman name of Paris (Lutetia), and *Bartonian* from Barton in Hampshire.

Thanetian.—Glauconitic sands which appear to be about the age of our Thanet Beds are found all along the northern and eastern borders of the Paris Basin, and as a rule they rest directly on the Chalk. Such are the sands of Watten and St. Omer near Calais, which are characterised by *Cyprina planata* and are often indurated by a siliceous cement into a stone known as *tuffeau*, resembling gaize or malmstone and containing diatoms and sponge spicules. Farther south in the Aisne are the sands of La Fère and of Châlons-sur-Vesle, which seem to be of the same age, while westward near Beauvais are the sands of Bracheux, containing *Cyprina planata*, *Ostrea bellovacina*, *Pectunculus terebratularis*, etc., a fauna which is classed as Thanetian by the majority of French geologists, but as Sparnacian by Professor Prestwich.[13] None of these sands extend so far as Paris.

In Belgium the Montian limestone (see p. 450) is overlain by glauconitic sands which are known as the Lower Landenian and unquestionably correspond to our Thanet Beds. Near Gelinden there are local beds of white marl which contain a few marine shells and many plant-remains which form an interesting early Eocene flora. Of the eighteen species of mollusca twelve occur in the Lower Landenian.

Sparnacian.—This group corresponds very closely to our Woolwich and Reading Beds. Near Paris it consists principally of plastic clays, but at the base is a conglomerate with bones of mammals and birds, overlain by laminated clay containing *Physa*, *Viviparus*, and *Unio*, and near the top is a bed of sand with seams of lignite. This sand and lignite thickens eastward, while the plastic clays die out, till in the Soissonnais the group is represented by beds of lignite and black clays with associated marls and sands (30 to 50 feet). These contain *Cyrena cuneiformis*, *Melania inquinata*, and other Woolwich species. The highest beds are found at Sinceny on the Oise. They contain the same freshwater shells and consist of sands and clays with rolled flint pebbles.

In Belgium there is a similar group of freshwater beds.

Yprèsian.—In France the London Clay is only found near

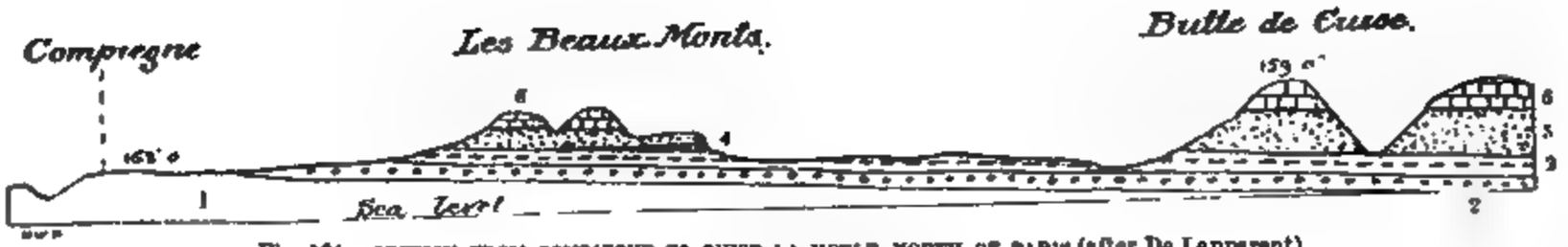

Fig. 164.—SECTION FROM COMPIEGNE TO OUISE LA MOTTE, NORTH OF PARIS (after De Lapparent).

6. Calcaire Grossier.
5. Sands of Cuise.
4. Lacustrine limestone.
3. Plastic clay and lignites.
2. Sands of Brachenx.
1. Upper Chalk.

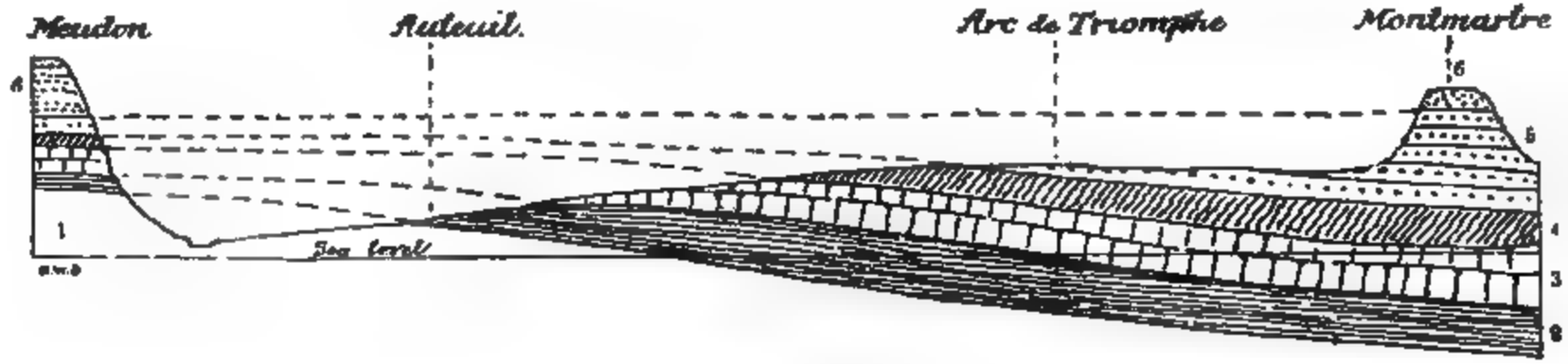

Fig. 165.—DIAGRAM SHOWING THE POSITION OF THE EOCENE DEPOSITS UNDER PARIS (De Lapparent).

6. Oligocene Sands.
5. Gypsum Beds.
4. Sables Moyens and Calcaire de St. Ouen.
3. Calcaire Grossier.
2. Plastic Clay.
1. Upper Chalk.

For these figures I am indebted to Messrs. G. F. Harris and H. W. Burrows and the Council of the Geologists' Association.

Calais and Orchies; evidently it thinned out southward and does not appear to be represented elsewhere unless by the lower part of the sands of the Soissonnais, which are not more than 160 feet thick. These are divisible into three portions :—

Sables de Cuise with *Cyrena Gravesi* and freshwater shells.
Sables de Pierrefonds, *Turritella edita* and *Nummulites planulatus*.
Sables d'Aizy with *Rostellaria Geoffroyi*.

In Belgium the Argile de Flandres corresponds with our London clay and is 480 feet thick in a boring at Ostende. Above it are sands with *Turritella edita* and *Nummulites planulatus*, which are evidently a marine equivalent of our Bagshot sands.

Lutétian.—In the Paris Basin this stage consists of the beds generally known as the Calcaire Grossier. It is the most fossiliferous formation in the Paris basin, and the middle portion yields the light yellow calcareous freestone which is the chief building-stone of Paris. The group is divisible into three substages as follows :—

	Feet.
3. Upper, thin-bedded fissile limestones with white and green marls and some beds of siliceous and dolomitic limestone, *Cardium obliquum*, *Cerithium denticulatum*, *Potamides lapidum*, *Lucina saxorum*	30 to 79
2. Soft thick-bedded limestones, some beds largely composed of *Miliola* and *Orbitolites*: *Cardium granulosum*, *Chama calcarata*, *Fusus bulbiformis*, *Turritella imbricataria* .	25 to 40
1. Glauconitic limestones and sands with a layer of pebbles at the base, *Cerithium giganteum*, *Cardium porulosum*, *Ostrea flabellula*, *Nummulites lævigatus* . . .	25 to 70
	80 to 145

In Belgium all the beds above the Argile de Flanders are sands. The Bruxellian consists of white and yellow sands with *Cardita planicosta*, *Pectunculus pulvinatus*, and a thin bed at the top full of *Nummulites lævigatus*, and the Laekinian sands contain *Cerithium giganteum*, *Turritella imbricataria*, and a layer full of small Nummulites at the top.

Bartonian.—The Calcaire Grossier of the Paris Basin is succeeded by a group of sands, sandstones, and marls from 30 to 50 feet thick, and known as the Sables de Beauchamp. The lower part of these sands contains *Nummulites variolarius*, and are sometimes grouped as Lutétian ; the middle portion yields *Cerithium mutabile*, *Xenophora agglutinans*, *Arca biangula*, etc., and the upper part corresponds to our Barton Sands with *Potamides pleurotomoides*. Resting on these sands are the limestones of St. Ouen, a set of white marly freshwater limestones with *Limnæa longiscata*, *Planorbis*

goniobasis, etc., formerly regarded as the base of the Oligocene series, but near Marines and Cresnes, north-west of Paris, they are associated with sands (the Sables de Monceux) containing Bartonian fossils (*Voluta athleta*, *Natica ambulacrum*, etc.).

The Wemmelian of Belgium has a basement bed of gravelly sand containing *Nummulites variolarius*, succeeded by calcareous shelly sandstones with *Turritella sulcifera* and *Tellina rostralis* and sandy clays containing many Barton fossils.

From the thicknesses given on the table on p. 484 it will be seen that neither the French nor the Belgian series attains anything like the thickness of the British Eocene, the French series having an average thickness of only 460 feet and the Belgian one of about 900 feet, whereas the English series in the Hampshire basin is from 1400 to 1500 feet thick.

Physical and Geographical Conditions

The gradual upheaval of the British area, which took place at the close of the Cretaceous epoch, was continued until the greater part of our islands was raised above the level of the sea and once more became part of a continent which stretched far westward and southward of their present limits. In imagining the aspect of this land we must remember that a large part of it was the upraised bottom of the Cretaceous ocean, and though, doubtless, portions of the Chalk were removed by erosion during upheaval, especially those which bordered the rising coast-lines of Wales and other hilly districts, yet we must suppose that the great sheets of chalk which occupied the intervening tracts would escape total destruction, and would form plains uniting Wales to the Pennine range and Ireland to England and Scotland. The Jurassic rocks must have been entirely concealed, and the strata exposed to subaerial waste would be the Chalk and the Palæozoic rocks of what we call the western and northern highlands.

The upheaval does not seem to have been quite a uniform movement, but to have been more rapid in the west and north than in the south-east, and it is probable that Ireland and Scotland were raised to a much higher level than that which they now occupy. It is supposed indeed that not only were they united to one another by a broad plateau, but also to the Faroe Islands and to Iceland; at the present time an uplift of at least 3000 feet would be necessary to effect such a union. It was this region that became the scene of the great volcanic activity which was described on p. 482.

With regard to the southern and eastern parts of England, the

great erosion which the Chalk has suffered beneath the London basin makes it probable that the greater part of it was raised into dry land, but it is not likely that it was ever lifted very far above the level of the early Eocene sea. Moreover, the east and west anticlinal axes of the Weald seem to have been initiated during the formation of these Eocenes, for the Woolwich Beds overlap the Thanet Sands southward as well as westward, and the Oldhaven pebble beds overlap all the underlying deposits so as to rest directly upon the Chalk near the edge of the North Downs; hence, as Mr. Whitaker remarks, "one is warranted in concluding that the planing down of the chalk that once spread over the Wealden tract began in Lower Eocence times, and that the pebble beds of Bromley, Blackheath, etc., are one of the direct results of that denudation."

Coming now to the area within which sedimentation was taking place, it is evident from a comparison of the English and Belgian strata that Belgium came within the influence of the Eocene sea before England did, and that a movement of depression allowed the sea to advance westward and to occupy portions of Kent, Surrey, Essex, and Suffolk at the time of the Thanet Sands.

Passing to the Reading Beds, we find evidence in their wider extension of a further and more general subsidence, which carried the sea over the whole of the London Basin, and southward over Hampshire into the southern basin. In the shallow gulf thus formed the marine basal beds of the Reading group were deposited, but there is no evidence that these beds ever extended over the area of the Weald. Moreover, the sea only retained possession of this area for a short time, for it is generally believed that the mottled clays of the Reading group are of freshwater origin. Their association with plant beds and their actual intercalation between freshwater deposits near Paris are strong pieces of evidence in favour of this view; but if they are freshwater beds, it is difficult to see how they can have been formed in anything but a large lake or series of lakes, and we may suppose that beaches or sand-dunes were thrown up which converted the greater part of the area into brackish or freshwater lakes.

The estuarine beds of the Woolwich facies were evidently formed in the estuaries and deltas of small rivers, and there is no reason for supposing that these rivers came from the west, but much reason to think that they drained a tract of land over the Wealden area, for they only occur on the northern and southern sides of the central part of this area.

During the deposition of the London Clay further subsidence took place, and the sea not only occupied all the area covered by the Reading Beds but extended somewhat beyond it. Mr. J. S.

Gardner remarks, "Throughout the deposition of the London Clay the subsidence of the sea-bed must have been quiet and gradual. The marine fauna, although still seen by comparison with those of succeeding beds to be relatively temperate-looking, and to belong to the Northern sea, has a far more torrid aspect. This is owing to a warmer period having set in, produced probably by the rise of land between England and North America, which, there is evidence to show, took place about this time, and completely shut off the cold Arctic currents. The temperature of the sea thus increased, doubtless acted upon the land, and enabled a tropical and most luxuriant and varied fauna and flora to migrate thither and become established. Myriads of fruits and seeds, and the bones of many species of turtle and crocodile, whose habits would cause them to be buried in such a position, as well as of snakes, birds, etc., are found at Sheppey just as they were stranded and buried in the delta-mud of the great western river."

In the succeeding deposits of the Lower Bagshot group we have proof of the silting up of this gulf, the more western beds of Corfe, Studland, and Alum Bay having been accumulated, according to Mr. Gardner, in a wide valley or shallow lake, and he remarks that "the complexity of the stratification suggests that two rivers united in this valley, and shows plainly that the waters must, in any case, have been rapid at times, and subject to periodical fluctuations of volume.

"In the Bournemouth Beds we have deposits of the same river, but in a more open and level valley, and in a closer proximity to the sea. In all the lower or freshwater series we have no sign of the presence of sea water, and when we do find it in the higher beds to the east, it is not that the river deposits encroached there on the sea, but that the land gradually sank and allowed the sea to cover them.

"It is of great interest to trace through these beds the change from a comparatively upland floor to a valley, and then to a swamp flora; to follow out the lowering of the land until it became sea; to trace the sea, first trickling in, as it were, and forming lagoons, then overwhelming the mud deposits formed by these lagoons, with shingle and sand; to realise, in fact, the actual shore-line, now marked by river deposits, full of plant-remains on one side, and a sea fauna with sharks' teeth on the other."

The Bracklesham series proper of Bracklesham and Whitecliff Bay are deposits formed in the sea outside the mouths of the rivers above mentioned. When their fauna is compared with that of the London Clay it is seen that its character is much more tropical, many southern types of mollusca being present, such as *Conus*,

Cypræa, *Pyrula*, *Mitra*, and *Bulla*, which are scarcely represented in the London Clay. The general aspect of the fauna is different, and very few species are common to both formations, though they are separated by only 100 to 150 feet of sands, which probably represent but a short epoch of geological time.

This difference of fauna was due probably to the opening of a communication with the southern (Nummulitic) sea, and it is believed that this opening was westward along the course of the existing English Channel between Cornwall and Brittany. But the deposition of the Bracklesham Beds and of the Calcaire Grossier of the Paris Basin seems to mark the maximum degree of the Eocene subsidence, and the communication with the outer ocean seems to have been of short duration. The fauna of the Barton Clay, though similar to that of the Bracklesham Beds, also recalls that of the London Clay, many of the species found in the latter but not in the Bracklesham Beds reappearing in the Bartonian, while at the same time a number of the more tropical Bracklesham species have disappeared.

This change can best be explained by a general upheaval of the whole region, an upheaval which may have closed the western passage, and must gradually have narrowed the sea spaces over England and Northern France till the greater part was converted into a shallow sea in which only sands and sandy clays were deposited. Whether this shallow sea opened westward or north-eastward into the Belgian sea is rather doubtful, but French geologists are inclined to the former view and think the western passage was not completely closed. If, however, there was a land barrier between the Belgian and the Parisian basins it is difficult to see how the northern species regained admittance to the more southern basin.

B. Oligocene Series

The name *Oligocene* was proposed for this series by Professor Beyrich in 1854, who showed that it contained an important fauna which differs considerably from that of the typical Eocene strata of England, France, and Belgium, and that it attained a considerable development in Northern Germany. The older classification arranged these beds partly in the Eocene and partly in the Miocene system, but this rendered it necessary to draw a line of separation between the two so-called systems in every area of deposition, and in the midst of a perfectly continuous series. The difficulty of making this separation, and the close connection of the faunas of the groups which were formerly called "Upper Eocene" and "Lower Miocene" respectively, has induced geologists

to accept Professor Beyrich's suggestion to unite these groups under the name of Oligocene.

The following are the divisions which have been made in the Oligocene series of England which has only been found in Hampshire and the Isle of Wight :—

		Feet.
Upper.—Not represented.		
Middle	Hamstead Beds	256
	Bembridge and Osborne Beds	174 to 240
Lower.—Headon Beds		160 to 212
		590 to 708

Characteristic Fossils

The general characters of the fauna have been described on p. 461. The following are species which are either restricted to or most abundant in each of the groups, but many species range from Headon to Bembridge Beds :—

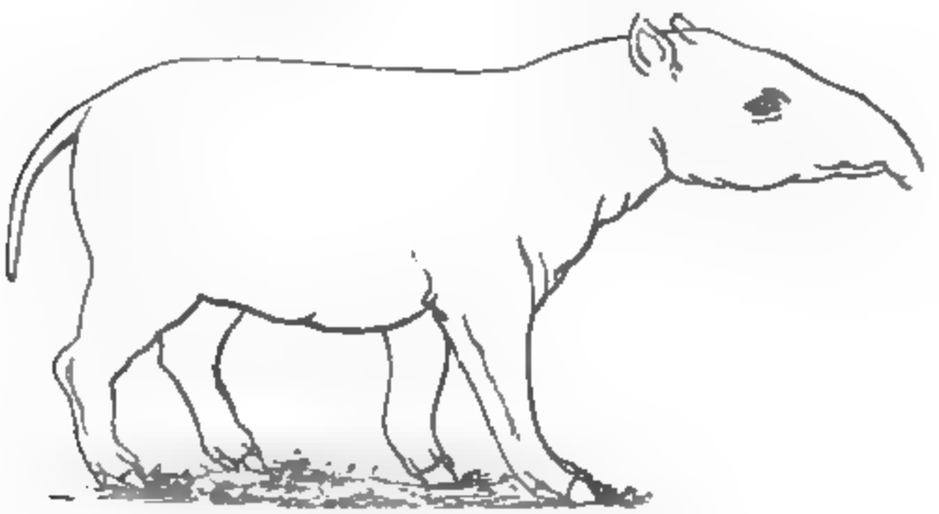

Fig. 166.—Restoration of Palæotherium magnum.

Fossils of the Headon Beds

Actinozoa. Solenastrea cellulosa, Litharea brockenhursti, Madrepora anglica.

Lamellibranchia. In the marine beds are: Cardita deltoidea, Corbula cuspidata, Cytherea incrassata, Nucula headonensis, Ostrea velata, Trigonocœlia deltoidea. In the freshwater beds are: Cyrena obovata, C. cycladiformis, Erodona (= Potamomya) plana, P. gregaria, Unio Solandri.

Gastropoda. In the marine beds are: Ancilla buccinoides, Cancellaria elongata, C. muricata, Neritina aperta, N. concava, Pisania labiata, Voluta spinosa, V. geminata, V. decora. In the freshwater beds: Potamides concavus, P. ventricosus, P. vagus, Limnæa longiscata, Melanopsis fusiformis, Nematura parvula, Planorbis euomphalus, P. lens, Helix occlusus.

Mammalia. Dacrytherium ovinum, Dichodon cervinus, Microchœrus erinaceus, Hyænodon minor, Palæotherium crassum.

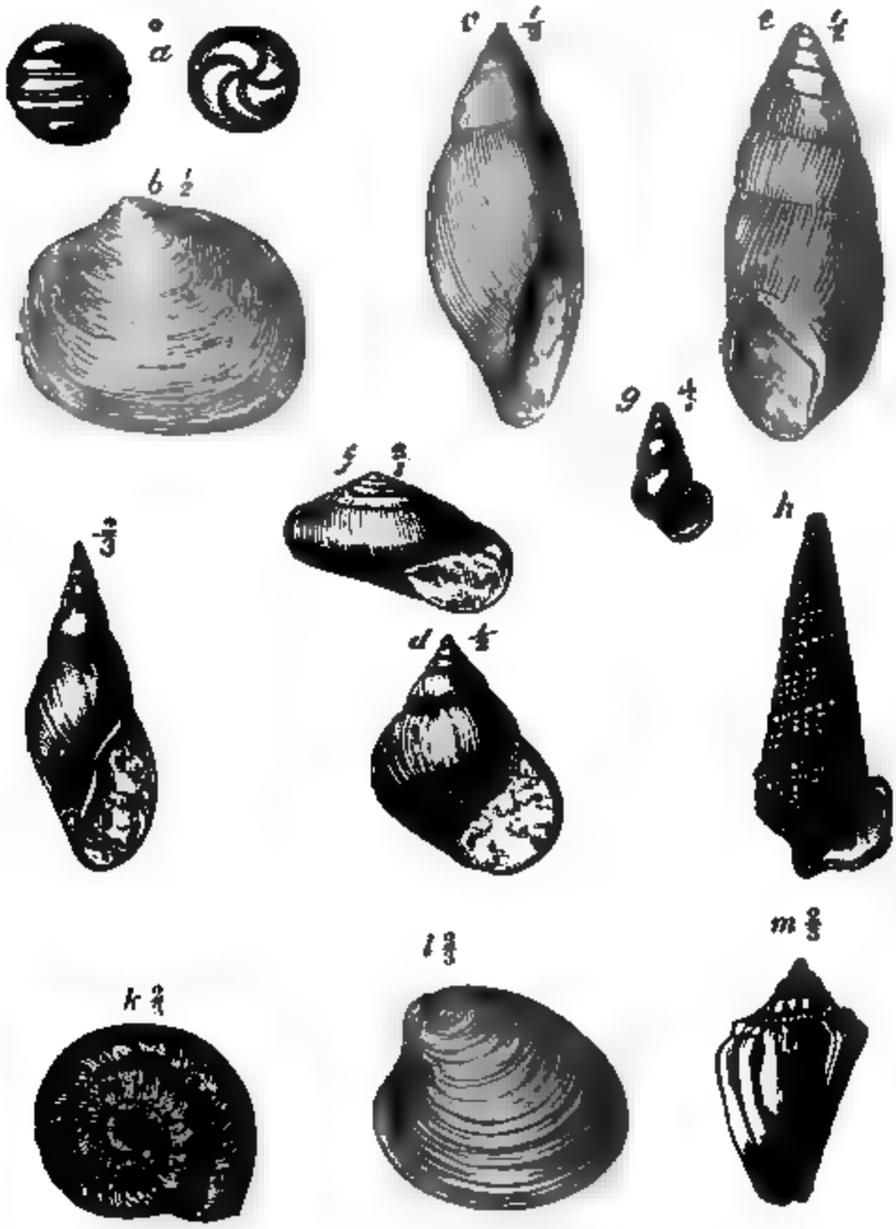

Fig. 167.—GROUP OF OLIGOCENE FOSSILS.

a. Chara medicaginula.
b. Cyrena pulchra.
c. Glandina costellata.
d. Viviparus anguloeus.
e. Amphidromus ellipticus.
f. Helix d'Urbani.
g. Tomichia Chastoli.
h. Potamides elegans.
i. Limnæa longiscata.
k. Planorbis euomphalus.
l. Cytherea incrassata.
m. Voluta Rathieri.

Fossils of the Osborne and Bembridge Beds

Plantæ. Chara Lyelli, C. medicaginula, Flabellaria lamanonis (a palm), Cinnamomum sp.

Lamellibranchia. Cyrena (Corbicula) semistriata, C. pulchra, C. obtusa, Ostrea vectensis, Arca Websteri.
Gastropoda. Glandina costellata, Amphidromus ellipticus, Cyclotus cinctus, Helix d'Urbani, H. pseudo-globosa, Viviparus lentus, Planorbis discus, Melania acuta, M. excavata, M. (Potomaclis) turritissima, Cerithium mutabile.
Mammalia. Anoplotherium commune, Chœropotamus gypsorum, Palæotherium magnum, P. medium, Xiphodon gracilis.

Fossils of the Hamstead Beds

Plantæ. Chara tuberculata, Andromeda reticulata, Arthrotaxis sp.
Lamellibranchia. Corbula subpisum, C. vectensis, Cytherea Lyelli, Ostrea callifera, O. cyathula, Panopea minor, Unio Gibbsi.
Gastropoda. Potamides (Terebralia) plicatum, Hydrobia (Tomichia) Chasteli, Melania (Bayania) fasciata, Neritina tristis, Nematura pupa, Voluta Rathieri.
Mammalia. Hyopotamus bovinus, Anthracotherium minus.

The following species are found more or less abundantly in all three sets of beds :—

Lamellibranchia. Corbula pisum.
Gastropoda. Cerithium mutabile, Potamides elegans, Hydrobia (Tomichia) Chasteli, Melania (Bayania) fasciata, M. acuta, Melanopsis carinata, Natica labellata, Neritina concava, Viviparus lentus, V. angulosus, Planorbis obtusus, P. platystoma.
Reptilia. Trionyx incrassatus (a freshwater tortoise).

Stratigraphy

The English Series

Headon Beds.—This group is divisible into three portions, Lower, Middle, and Upper, the middle portion containing marine and brackish-water shells, while the lower and upper are of fresh-water origin. These beds underlie all the northern part of the Isle of Wight, but except at the western end their outcrop is very narrow. They are well exposed in the cliffs which extend from Headon Hill to Cliff End, and also in Whitecliff Bay at the east end of the island (see map, Fig. 146). In Hampshire they underlie a large part of the New Forest, and the Lower Headon is shown on the coast in Hordwell Cliff.

The section at Headon Hill may be regarded as the typical one, although the total thickness is less there than elsewhere. The succession at this place is as follows :—[14]

		Feet.
Upper Headon, 46 feet	Variegated clays with *Erodona* (*Potamomya*) *gregaria*	21
	Limestone with *Limnæa longiscata* and *Planorbis euomphalus*	8
	Blue clays with the same *Limnæa* and *Planorbis*	5
	Limestone with the same fossils and 2 feet of sand below	12

		Feet.
Middle Headon, 33 feet	Clays with *Potamides concavus*, *Cyrena obovata*, etc.	7
	Limestone with *Limnæa* and *Planorbis*	1
	Sandy clays with marine fossils	15
	Sand and clays with *Neritina*, *Cyrena*, and *Cerithium*	10
Lower Headon, 67 feet	Limestone with *Limnæa* and *Planorbis*	3
	Sands and clays with carbonaceous layers and lignite	20
	Clays and sands with two beds of limestone, *Viviparus angulosus*, *Nematura parvula*, *Limnæa*, and *Planorbis*	25
	Sands and clays with *Erodona plana*, etc.	19

In Colwell Bay the Upper Headon consists mainly of clays and sands, the limestones being reduced to 1 and 3 feet respectively; the Middle Headon there also contains many marine shells, such as *Ostrea velata*, *Cytherea incrassata*, *Corbula cuspidata*, *Nucula headonensis*, while the Lower Headon is thicker (83 feet). In Whitecliff Bay the marine beds have expanded to 126 feet, and contain many of the Brocklehurst shells mentioned below, while the Lower Headon freshwater beds are reduced to 28 feet, a fact which suggests that part of these lower beds may be replaced by marine deposits.

The marine beds are found also at Brockenhurst and Lyndhurst in the New Forest, where they yield a rich fauna; 150 species of shells and corals have been found there, about half of which range up from the Barton Beds, but the fauna as a whole closely resembles that of the Tongrien in Belgium and Germany. Some of the commonest species are *Rimella rimosa*, *Cancellaria muricata*, *Pisania labiata*, *Pleurotomaria transversaria*, *Voluta decora*, *V. geminata*, *Cardita deltoidea*, *Cytherea incrassata*, *Corbula cuspidata*, with *Solenastrea cellulosa* and many other corals.

At Hordwell only the Lower Headon is exposed and the beds are freshwater with a thickness of 83 feet.[15] Many reptilian and mammalian remains have been found at this locality.

Bembridge Group.—The lower beds of this group were originally included by Webster 1816, with the Upper Headon Beds, but were separated by Professor Forbes in 1853, under the name of the St. Helens Beds, afterwards changed to "Osborne Beds." Under the latter name they are described in the *Memoirs of the Geological Survey*, and have received a separate colour on the map, but as the fossils they contain are not distinctive, and are all of freshwater species, they are certainly not entitled to rank as a primary division. Mr. Keeping agrees with Professor Judd in grouping them with the overlying Bembridge group under the name of Lower Bembridge marls.[16] This appears the most reasonable and simple classification, and if this is adopted the Bembridge group will consist of three members, as below :—

	Hamstead and Headon.	Whitecliff.
3. Upper marls	75	106
2. Bembridge Limestone	15	25
1. Lower marls and Osborne Beds . .	74	80
	164	211

The Lower or Osborne marls at Headon Hill and Colwell Bay consist of white, blue, and red marls with calcareous concretions which contain *Limnæa longiscata*, *Planorbis discus*, *Viviparus lentus*, and other freshwater shells. At Whitecliff Bay they consist of dark green clays and sands, but are much concealed by landslips, and the best sections occur along the north-eastern coast from Osborne to Nettlestone Point; here, however, they assume a very different facies, the lower 20 feet consisting of marls, with bands of hard yellowish sandy ragstone and shell limestone full of *Viviparus lentus* and *Melania excavata* (Nettlestone Beds), the upper 50 feet consisting of green and yellow sands alternating with marls and clays of white, green, and yellow tints (St. Helens sands), well seen at Priory Point, where they contain *Melania excavata*, *Planorbis obtusus*, *Limnæa longiscata*, and *Cyrenæ*.

The Bembridge Limestone is a cream-coloured stone with interstratified marls; sometimes it is compact, sometimes quite tufaceous and concretionary; it is quarried at Headon Hill, at Sconce near Cliff End, and at Binstead near Ryde, and it is also exposed at Bembridge Point and in Whitecliff Bay. Its contents are terrestrial and freshwater, many species of *Helix*, *Amphidromus*, *Achatina*, *Glandina*, *Cyclotus*, *Clausilia*, *Limnæa*, *Planorbis*, and *Viviparus* occurring, with oviform bodies which are supposed to be the eggs of the large *Amphidromus*; stems and seeds of *Chara* are common, and mammalian remains are found in the Binstead quarries.

The Upper Bembridge marls extend from the river Yar to Bembridge and Foreland Point, and occupy some space round Osborne, Ryde, and St. Helens. At St. Helens they are 120 feet thick, but diminish westward to 70 or 75. At Hamstead they consist entirely of freshwater beds, chiefly blue and green clays containing *Viviparus lentus*, *Melania acuta*, *Potamaclis turritissima*, *Melanopsis carinata*, *Cyrena semistriata*, and *C. pulchra*.

In Whitecliff Bay there is a marine bed near the base of these marls containing *Ostrea vectensis*, *Cytherea incrassata*, *Nucula similis*, and *Mytilus affinis*. Above are marls with *Potamides* and *Cyrena*. About 50 feet up is a gray sandy limestone (4 feet thick) containing *Amphidromus ellipticus*, *Glandina costellata*, *Limnæa longiscata*, etc., and the highest beds contain *Potamaclis turritissima* in abundance.

The Hamstead Beds cover a large area extending from

Yarmouth and Hamstead through Parkhurst Forest and across the Medina river to Brading Harbour. Throughout this tract they maintain a thickness of over 200 feet, and their base is everywhere marked by a band of carbonaceous clay. At Hamstead the succession is given by Mr. Reid as follows :—

	Feet.
Marine Beds with *Corbula vectensis*, *C. pisum*, *Ostrea callifera*, *Voluta Rathieri*, *Potamides plicatum*, *P. elegans* . . .	31
Leaf and Seed Beds.—Red and green clays with carbonaceous layers containing leaves of palms and water-lilies and seeds . .	153
White Band.—Green clay with white shelly marls . . .	6
Nematura Beds.—Green and black clays with *Nematura pupa*, *Assiminea conica*, *Sphærium Bristovi*, *Hydrobia* (*Tomichia*) *Chasteli*	64
Black Band.—Black clay with *Viviparus lenta* and *Unio* . .	2
	256

The "white band" is only traceable as far as Parkhurst Forest, but east of the Medina it appears to be represented by a bed of fine sand which, commencing near Newport, thickens eastward till it is about 40 feet and forms a marked feature on the surface.

The Oligocene in Belgium and France

As in the case of the Eocene series, the Oligocene deposits which are found in Belgium and Northern France can be correlated without much difficulty with those of our own country, but those of France include beds which appear to be higher and newer than any which occur in England or Belgium; to these the name of *Aquitanian* has been given because of their large development in Aquitaine. Again, in the central part of France there are lacustrine deposits of great thickness containing many fossils of great interest and associated with volcanic phenomena.

The accompanying table shows the Oligocene succession in the three most important French districts, grouped into the four stages adopted by Professor de Lapparent and correlated with the Belgian and English stages, but it should be mentioned that some French geologists regard the *Ludian* and its equivalents as the uppermost member of the Eocene series.

1. *Belgium*

The Oligocene occupies a large area in Belgium, and though the beds differ considerably in lithological character from those of the Hampshire basin, the general succession corresponds very closely with that of our country. Belgian geologists have divided them into two stages : (1) the *Tongrian*, from Tongres near Limbourg, and

CORRELATION OF OLIGOCENE SERIES IN ENGLAND, BELGIUM, AND FRANCE

English Stages.	Belgian Stages.	French Stages.	Strata of Paris Basin.	Strata in Aquitaine.	Strata in the Limagne.
Wanting.	Wanting.	Aquitanian.	Sands of the Gatinais, Calcaire de la Beauce, Marls of Etampes, 200 feet.	Limestones of the Aginais, lacustrine at the top and marine in the lower part.	Marls and limestones with *Helix Ramondi*, *Limnæa*, and *Planorbis*, 330 feet.
Hamstead Beds.	Rupelian.	Etampian.	Sands and sandstone of Fontainebleau, Sands of Fontenay, Ostrea marls, 100 to 200 feet.	Molasse of the Aginais, Starfish limestones.	Sands and clays with *Cyrena semistriata* and *Potamides plicatus*, 220 feet.
Bembridge Beds.	Tongrian supérieur.	Sannoisian.	Calcaire de Brie, Green marls, Supra-gypseous marls, about 80 feet.	Limestone of Castillon, Molasse of Fronsadais, Marls of Medoc.	Sands and sandy clays with *Nystia plicata*, *N. Chasteli*, and *Melania arvernensis*, 160 feet.
Headon Beds.	Tongrian inférieur.	Ludian.	Gypsum series, Montmartre, etc., partly lacustrine, partly marine, 100 to 180 feet.	St. Estephe limestone, Operculina limestones of Biarritz.	Not represented.

(2) the *Rupelian*, from the river Rupel south of Antwerp, on which is situate the town of Boom.

Tongrian.—This appears to include the representatives of two stages, the Lower Tongrian corresponding with the Middle or Upper Headon Beds, and the Upper Tongrian with the Bembridge Beds. There is in most parts of Belgium a break between the Tongrian and the Eocene series, the Oligocene resting indifferently on various members of the lower series.[17] The Lower Tongrian is of small thickness, from 20 to 60 feet only, and consists of sands with *Ostrea ventilabrum*, *Astarte Omaliusi*, *Cytherea incrassata*, and *Cassis nodosa*, a marine fauna closely resembling that of Brocklehurst (Middle Headon).

The Upper Tongrian is an estuarine or fluvio-marine group, and comprises three members, as below, but the total thickness is only 20 to 30 feet.

3. Sands of Vieux Joncs with *Potamides plicatus* and *P. elegans.*
2. Green clays of Hénis with *Cytherea incrassata* and *Mya angustata.*
1. Sands of Bauterêm with *Cyrena semistriata*, *Potamides perditus*, *Melania acuta*, *Bithinia helicella*, and *B. plicata.*

Rupelian.—This is a purely marine formation, and appears to be the equivalent of our Hamstead Beds. It commences with the sands of Berg, characterised by the abundance of *Pectunculus obovatus*, with *Voluta Rathieri*, *Cominella Gossardi*, *Tritonium flandricum*, and locally it includes a band of clay with *Nucula compta.*

The Upper Rupelian consists of a thick mass of sandy clay, the Argile de Boom, which contains many fossils, some of the more important being *Voluta Rathieri*, *Fusus elongatus*, *Triton flandricum*, *Corbula pisum*, and *Nuculana deshayesiana;* it has also yielded many remains of vertebrates, including two Sirenians (*Halitherium*), several birds, turtles, and a number of fish, chiefly Elasmobranch, *Lamna*, *Odontaspis*, *Oxyrhina*, *Carcharodon*).

2. *Paris Basin*

The Oligocene succession in the Paris Basin is tabulated on p. 498. The *Ludian* or Gypsum Beds, though generally resting on the Calcaire de St. Ouen or the Sands of Monceux, sometimes lie directly on the sands of Mortefontaine and Fontainebleau. They consist of three or four massive beds of gypsum, alternating with beds of marl. The lower beds are marine; the lowest marl contains *Pholadomya ludensis*, *Cardium granulosum*, *Potamides tricarinatum*, and *Potamides concavus*, and the second has *Lucina inornata*, *Corbula subpisum*, and *Corbulomya Nysti.* The highest beds are lacustrine, and the highest bed of gypsum, which is 65 feet thick at

Montmartre, has yielded fifty species of mammalia, including *Palæotherium magnum*, *P. medium*, *Anoplotherium commune*, and *Xiphodon gracile*.

Sannoisian.—The Supra-gypseous Beds are blue and white marls with freshwater fossils, and the Green Marls are fluvio-marine, containing *Cyrena semistriata* (= *C. convexa*), *Cytherea incrassata*, *Psammobia plana*, *Potamides plicatus*, etc. The Calcaire de Brie consists of white freshwater marls with beds of siliceous limestone which have been used for making millstones (meulières).

Etampian.—The name of this stage is taken from the village of Etampes, about half-way between Paris and Orleans. Near Paris it commences with marls and light-coloured sands, often 150 feet thick, but thinning southwards to only 6 feet at Etampes. *Ostrea cyathula*, *O. longirostris*, and *Corbula subpisum* are abundant. The Sands of Fontenay are without fossils near Paris, but pass southwards into beds which contain *Pectunculus obovatus*, *Buccinum Gossardi*, *Potamides plicatus*, *Voluta Rathieri*, and *Triton flandricum*, which correlate them with the Rupelian of Belgium. They are very fossiliferous near Etrechy, Vauroux, and Pierrefitte. The highest member of this stage is that known as the Sables de Fontainebleau, which is correlated with the Sables d'Ormoy overlying the fossiliferous beds near Etampes; these sands are often infiltrated with calcite and compacted into calcareous sandstone.

Aquitanian.—Near Etampes the sands of Ormoy are succeeded by marls of freshwater origin containing *Bithinia Dubuissoni* and species of *Limnæa*, *Cyclostoma*, etc. This is succeeded by the Calcaire de la Beauce, which extends over a large part of the plateau between the valleys of the Seine and the Loire. It is entirely of lacustrine origin and is divisible into two thick masses of limestone, each about 60 feet thick, separated by a band of sandy clay 40 feet thick; the lower part is known as the *Limnæa* limestone, and the upper part as the *Helix* limestone, from the relative abundance of species belonging to these genera.

3. *Central France*

Extensive lakes also existed in Central France throughout the Oligocene period, and have left their monuments in the lacustrine strata of Auvergne, Cantal, and Velay. The northernmost of these lakes occupied the valley-plain of the Allier, known as the Limagne d'Auvergne; the average breadth of this tract is 20 miles, and its length from near Nevers to Brioude nearly 100 miles; it consists of nearly horizontal strata of sandstone, marl, and limestone, which often rise into low hills capped by

fragments of ancient lava-streams; this tract is bounded on either side by lofty hills of granite and gneiss, which rise to a height of 1600 feet above the plain, and 3000 feet above the sea, while the western ridge supports a chain of extinct volcanoes, whence lava-streams flowed from time to time into the valleys below.[18]

The deposits of the plain exhibit the succession which is tabulated on p. 498. But these beds cannot all be seen in one locality; the arenaceous strata are probably thickest near the margins of the ancient lake, while the marls and limestones constitute a central deposit which is about 700 feet thick. The lowest beds contain few fossils, but bones of *Palæotherium* have been found; the marls have yielded a large assemblage of fossils — ungulates, carnivora, rodents, opossums, birds, crocodiles, tortoises, and snakes, with numerous land and freshwater molluscs; small ostracod crustacea (*Cyprides*) also abound in the marls.

Some of the limestones are oolitic, others are entirely made up of the cases of caddis worms cemented together by calcareous matter, and in the Cantal there is a chalky limestone containing siliceous nodules like our flints.

The mammalia belong to the genera *Palæotherium*, *Anthracotherium*, *Paloplotherium*, *Entelodon*, *Rhinoceros*, *Cœnotherium*, *Dremotherium*, and *Amphitragalus*.

4. *Aquitaine*

The most continuous succession in this region is found near Blaye, where the freshwater Eocene limestone (see p. 484) is overlain by the marine limestone of St. Estephe, which corresponds to the Gypsum Beds of Paris. This is succeeded by marls with *Anomia girondica* and fluvio-marine beds containing *Ostrea cyathula*, *O. longirostris*, and bones of *Xiphodon* and *Paloplotherium*, and comparable with our Bembridge Beds. The Etampian or Hamstead group is represented by a thick mass of yellowish limestone with marine fossils, including the starfish *Crenaster lævis* and many other echinoderms. Finally, there is an important and varied group of deposits forming the Upper Oligocene or Aquitanian stage; in the Bordelais (Bordeaux district) the beds are all marine, but these pass eastward into estuarine and lacustrine deposits (Bazadais type) containing the characteristic *Helix Ramondi* and *Cyclostoma antiquum* with species of *Limnæa* and *Planorbis* and mammalian remains.

5. *Switzerland*

An immense lacustrine area, sometimes invaded by the sea, existed in Switzerland during Oligocene and Miocene times, the

strata accumulated within its limits attaining a thickness of 7000 or 8000 feet.

"Nothing," says Jukes, "is more calculated to strike the geological traveller on his first visit to Switzerland than the vast deposit of the 'Molasse,' occupying the central region between the Alps and the Jura. This is the country of the great lakes, extending from that of Geneva to that of Constance. The hills by which these lakes are environed have all the rugged and broken character of mountains, and rise in peaks of various altitudes up to that of 6050 feet, which is the height of Rhigi Kulm. These hills, which, if they were not overshadowed by the still loftier Alps, would themselves be celebrated mountains, are composed from top to bottom of beds of sand and gravel, occasionally compacted into sandstones and conglomerate."

The lowest beds are marine, and appear to be of the same age as the Rupelian Beds of Belgium; their thickness is about 1000 feet. These are overlain by the "red molasse," which consists of red conglomerates, sandstones, and marls, and the portion which is referable to the Oligocene attains a thickness of 1300 feet; from these beds a large number of plant-remains have been collected, including species of *Sequoia*, alders, birches, figs, laurels, cinnamon-trees, and evergreen oaks.

Physical and Geographical Conditions

At the beginning of Oligocene time the geography of the British area seems to have been as follows:—to the east of England there was a sea covering Belgium and a part of the North Sea and extending eastward over Germany, while a smaller and shallower sea lay over the Parisian basin and stretched thence north-westward across the English Channel into Hampshire, and reaching perhaps into North Dorset and Somerset. Whether there was any communication between these two seas across what is now the plateau of the Ardennes is a doubtful point on which French and Belgian geologists are not yet agreed; it is also doubtful whether there was any opening westward into the Atlantic, but there must have been a connection with the open sea either on the one side or the other.

The coasts of the Anglo-Parisian sea were probably low and swampy, backed by extensive tracts of low-lying ground which were inhabited by a large number of mammalian animals, the remote ancestors of the tapirs, rhinoceroses, hogs, deer, and carnivores of the present day. The western part of Britain, including the land which in all probability then united Ireland to Wales and Cornwall,

was a region of hills and mountains, among which many large rivers had their origin. One of these rivers probably ran through the vale of the Bristol Channel and emptied itself into the estuarine termination of the Hampshire gulf, and a second river flowing from the direction of the Severn valley may have ended in the same gulf.

The Headon Beds present us with a section through part of the delta of this river. The alternation of marine, brackish, and freshwater beds is due partly to the process of subsidence and silting up, partly perhaps to change in the course of the river channel, but the northerly and easterly increase of the marine strata (Brockenhurst Beds) and the southerly increase of the freshwater limestones are facts which prove the deepest part of the estuary to have lain to the north-east of the Isle of Wight, and to have trended from north-west to south-east.

The muddy flats of this estuary swarmed with *Cerithiidæ*, *Cyrenidæ*, etc., while the pools of the delta were peopled by species of *Planorbis*, *Limnæa*, *Viviparus*, etc., the dead shells of which were swept down into the lower reaches of the river; crocodiles, gavials, and turtles abounded in its waters as in those of modern tropical rivers, and its banks seem to have been clothed with a luxuriant vegetation of reeds, ferns, and palms.

The same conditions prevailed during the formation of the Bembridge and Hamstead Beds, with local variations, till we reach the more purely marine beds at the summit of the Hamstead group, from which we must infer that part of the estuarine area was re-occupied by the sea, and it seems probable that this was due to subsidence.

When we consider that the whole of the British Oligocene series consists of shallow-water deposits, it is evident that a certain amount of subsidence must have taken place during the period in order to allow of the accumulation of such a thickness of beds (600 feet). The Belgian succession and the comparatively deep-water character of the argile de Boom, which is generally regarded as the equivalent of our Hamstead Beds, point to the same conclusion. It is probable, however, that this subsidence was more or less limited to the basins of deposition, and it may have been contemporaneous with and complementary to a rise of the Wealden axis.

The records of the Hampshire delta are here abruptly broken off, and we have no means of ascertaining the last phases of its history; we can only guess from the analogy of the French deposits that there was a gradual upheaval of the whole area, and that the depressions of this terrestrial surface were occupied

by large lakes. Whether any such lakes existed on British ground we do not know, but many were scattered through the centre of Europe, in France, Switzerland, Germany, and Austria.

The following is Lyell's picture of the Auvergne lakes in Oligocene times :—

"There was first a period when the spacious lakes, of which we may still trace the boundaries, lay at the foot of (granitic) mountains of moderate elevation, unbroken by the bold peaks and precipices of Mont Dor, and unadorned by the picturesque outline of the Puy de Dome, or of the volcanic cones and craters now covering the granitic platform. During this earlier scene of repose deltas were slowly formed ; beds of marl and sand several hundred feet thick deposited ; siliceous and calcareous rocks precipitated from the waters of mineral springs ; shells and insects embedded, together with the remains of the crocodile and tortoise ; the eggs and bones of water-birds, and the skeletons of quadrupeds, most of them of genera and species characteristic of the Miocene (Oligocene) period. To this tranquil condition of the surface succeeded the era of volcanic eruption, when the lakes were drained and when the fertility of the mountainous district was probably enhanced by the igneous matter ejected from below, and poured down upon the more sterile granite."

References to Literature of Eocene and Oligocene

[1] See "Geology of the London Basin," *Mem. Geol. Survey*, vol. iv. (1872), and "Geology of London" (1889), both by Mr. W. Whitaker ; also the smaller *Guide to the Geology of London*, by the same author (sixth edition).

[2] "Bagshot Beds of the London Basin," by H. W. Monckton, *Quart. Journ. Geol. Soc.* vol. xxxix. p. 348 (1883).

[3] C. J. A. Meyer in *Quart. Journ. Geol. Soc.* vol. xxvii. p. 74.

[4] See "Geology of the Isle of Wight," *Mem. Geol. Survey*, second edition (1889).

[5] J. S. Gardner in *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 1, and *Proc. Geol. Assoc.* vol. vi. p. 88.

[6] Rev. O. Fisher in *Quart. Journ. Geol. Soc.* vol. xviii. p. 65.

[7] J. S. Gardner in *Quart. Journ. Geol. Soc.* vol. xxxv. p. 209.

[8] Gardner, Keeping, and Monckton on the Upper Eocene beds in *Quart. Journ. Geol. Soc.* vol. xliv. p. 578.

[9] J. S. Gardner in *Quart. Journ. Geol. Soc.* vol. xli. p. 87.

[10] *Ibid.* vol. xliii. p. 270.

[11] The *Volcanoes of Great Britain*, by Sir Archibald Geikie. See also A. Harker in *Geol. Mag.* Dec. 4, vol. viii. p. 506.

[12] *Traité de Géologie*, par. A. de Lapparent, fourth edition, 1900 ; see also *The Eocene and Oligocene Beds of the Paris Basin*, by G. F. Harris and H. W. Burrows (Geol. Assoc. 1891).

[13] Prestwich on the "Correlation of the Eocene Strata in England, Belgium, and France," *Quart. Journ. Geol. Soc.* vol. xliv. p. 88.

[14] See "Geology of the Isle of Wight," *Mem. Geol. Survey* (1889); also Keeping and Tawney in *Quart. Journ. Geol. Soc.* vol. xxxvii. p. 85.

[15] See Keeping and Tawney on the Hordwell section in *Quart. Journ. Geol. Soc.* vol. xxxix. p. 566.

[16] Professor J. W. Judd in *Quart. Journ. Geol. Soc.* vol. xxxvi. p. 169, and H. Keeping in *Geol. Mag.* Dec. 3, vol. iv. p. 48.

[17] See E. Van den Broeck, "Coup d'œil synthétique sur l'Oligocene Belge," *Bull. Soc. Belge de Géol.* tom. vii. p. 208 (1893).

[18] See the "Volcanic Region of Auvergne," by Canon T. G. Bonney in *Proc. Geol. Assoc.* vol. xvii. p. 191 (1901).

Additional References

"Geology of the Country around Dorchester," *Mem. Geol. Survey*, by C. Reid (1899).

Livret Guide des Excursions en France, of the Eighth International Geological Congress (1900). Includes the Geology of the Gironde, Aquitaine, Auvergne, and the Paris Basin.

CHAPTER XVII

NEOGENE SYSTEM

THE Newer Tertiary strata, *i.e.* those which are newer than the Oligocene series, have so much in common, both as regards their mode of occurrence and the species of fossils which they contain, that they can hardly be considered to form more than one system, and even when so grouped together it is only in the south and south-east of Europe that they constitute a series of deposits comparable in thickness and extent to those of older systems.

As explained on p. 458, the name Neogene will be adopted for this system, and it will be regarded as including the three groups or series which were termed Miocene, Pliocene, and Pleistocene by Lyell. It is true that many geologists, both in this country and on the Continent, exclude the Pleistocene from the Neogene system and place it in what they call a Quaternary or Post-Tertiary system, but the only essential difference between the Neogene and the Quaternary is that the remains of man have hitherto only been found in the latter. It would, however, be rash to say that man did not exist during the later part of Pliocene time, and thus the distinction on which a Quaternary system is based must be regarded as an assumption. No hard-and-fast line can be drawn between deposits of Pliocene and Pleistocene age, and from a purely geological point of view it is more logical and correct to say that Tertiary time merges into the Recent or Historic period than to imagine that Tertiary time ended when man first appeared.

When the Miocene, Pliocene, and Pleistocene groups were established by Lyell the percentage of living species of mollusca in each fauna was taken as a guide and as a criterion of age, but subsequent researches have shown that the percentages originally adopted by Lyell cannot be sustained, and that if the principle is to be retained the proportional numbers must be altered, and further, that much latitude must be allowed in certain cases. It may be considered,

however, that the Miocene molluscan fauna has only from ten to forty living species, the Pliocene from forty to ninety, and the Pleistocene from ninety to a fauna without species that are more than locally extinct, and finally to one that does not differ from that of the surrounding country or neighbouring sea.

Some geologists, however, prefer to take the mammalian faunas as a guide instead of the molluscan, and to take note of the extinction of genera rather than of the introduction of new species. Agreement on this question has not yet been reached, and there are differences of opinion as to the respective limits of the three groups. In this matter I shall follow the arrangement adopted by Mons. de Lapparent in the last edition of his *Traité de Géologie* (1900), except that it seems better to include the *Tortonian* under the *Helvetian*.

A. Miocene Series

Between the formation of the latest Oligocene deposits and the earliest Miocene beds of Western Europe there seems to have been a certain interval of time during which geographical changes of considerable magnitude took place, and, as a consequence, there is in most places a decided stratigraphical break between the strata of the two series. Thus in France the great lakes and lagoons of the Aquitanian epoch disappeared and the whole country appears to have been elevated into dry land; the same was the case in Belgium and in Germany, and for a time the whole of Northern Europe (including the British Islands) seems to have formed a compact continent.

When depression again took place, the sea did not everywhere re-enter the previous areas of deposition; the Atlantic did again cover a portion of Aquitaine, but it also spread into Touraine and along the valley of the Loire, and in both areas the Miocene deposits rest unconformably on those below. There are marine Miocene deposits in Southern Germany, but none in the northern part of that country, and it was not till near the close of the period that an arm of the sea entered Belgium, Holland, and Westphalia.

In South-eastern Europe and in the Mediterranean area there is a greater continuity between the Oligocene and Miocene, but a renewed subsidence carried marine Miocene deposits in many places over a wider area, while further uplifts in the Pyrenean, Alpine, and Apennine regions made these ranges much more prominent features than they had previously been.

With regard to the subdivision of the Miocene series, agreement has not yet been attained; but if the *Pontian* or *Pannonian* be

really separable from the *Sarmatian*, four stages may be admitted as shown in the accompanying table (see p. 510). No representative of this series has been found in the British Isles, and for the nearest deposits of Lower Miocene age we must go to the west of France, to Switzerland, and Austria ; they also occur in Italy and Greece, and again round the Black Sea, whence the name of *Pontian* has been given to the uppermost beds.

Life of the Period

The flora of the lower stages of the Miocene does not differ very greatly from that of the Oligocene period, and indicates a climate of sub-tropical warmth, but that of the later stages furnishes evidence of a certain diminution of temperature and probably of an increase of the winter's cold. It was during this period that palms ceased to be abundant in Central Europe.

One of the best-known floras is that of the Œninghen beds of Switzerland, from which no fewer than 475 species of plants were obtained by Professor Heer. These include a vine (*Vitis teutonica*), plane-trees (*Platanus aceroides*), maples (*Acer trilobatum*), cinnamons, figs, elms, liquidambars, cypresses (*Taxodium* and *Glyptostrobus*), with a few *Proteaceæ*. Looking to the Miocene flora as a whole, Professor Heer remarks that "increased prominence is given to the Japanese types by the abundance of camphor-trees and *Glyptostrobi;* to the Atlantic element by the laurels ; to the American types by the numerous evergreen-oaks, maples, poplars, planes, liquidambars, *Robiniæ*, *Sequoiæ*, *Taxodia*, and ternate-leaved pines ; and to the types of Asia Minor by the *Planeræ* and a species of poplar (*Populus mutabilis*). The greatest number and the most important of the types of the Swiss Miocene flora belong, therefore, to a belt lying between the isothermal lines of 59° and 77° Fahr., and in this zone America is now the region which is most correspondent to the natural character of the Swiss Miocene land."

Among invertebrate animals the echinoderms are perhaps the most noteworthy, and they are conspicuous members of the marine fauna in the French, Italian, and Austrian regions ; the principal genera are *Clypeaster*, *Amphiope*, *Scutella*, *Echinolampas*, *Spatangus*, and *Arbacia*.

The marine mollusca all belong to living genera, but form an assemblage which resembles that now found in the Caribbean Sea more than that of the existing Lusitanian and Mediterranean provinces, and the same is the case with the echinoderm fauna. In the brackish waters of Eastern Europe the bivalves *Congeria*, *Adacna*, *Monodacna*, and *Didacna* made their appearance and have left descendants in the Caspian Sea of the present day.

It is, however, the vertebrates, and especially the Mammalia, which form the most characteristic and distinctive features of the Miocene fauna. When this fauna is contrasted with that of the Oligocene the principal changes are seen to be as follow: (1) the appearance of Proboscidea in the genera *Dinotherium* and *Mastodon*; (2) the replacement of the Palæotheres and Anthracotheres by true rhinoceroses, both of the hornless (*Acerotherium*) and horned type (*Rhinoceros*); (3) the appearance of large cats (*Machærodus*) comparable to modern panthers and tigers; (4) the appearance of monkeys and apes; (5) the disappearance of marsupials from Europe.

The assemblage of animals was thus very different from that of Oligocene times, *Acerotherium*, *Anchitherium*, and *Amphicyon* being almost the only mammals that survived from the one period to the other.

The *Dinotherium* was remarkable for having two large tusks in the lower jaw, which curve downwards and are supposed to have been used by the animal to moor himself to the banks of the lakes in which he lived while he fed upon the herbage. The *Mastodon* had long tusks in both jaws, and was more like an elephant in build, and probably also in habits.

Small deer with horns made their appearance at this time, but the horns were very small; the pig tribe were represented by *Palæochœrus*, which first appears in the highest Oligocene of the Allier, and by *Hyotherium*, a closely allied genus. The carnivores include *Machœrodus* (the sabre-toothed tiger), *Hyœnarctos* (a bear-like animal), with otters (*Lutra*), cats, and foxes. Beavers made their dams across the streams; a gigantic ant-eater (*Macrotherium*) tore up the ant-hills with his great claws; lastly, true apes made their appearance, several forms being known (*Pliopithecus*, *Dryopithecus*, and *Oreopithecus*), the two former being anthropoid apes of large size, and the latter intermediate between these and the Barbary ape (*Macacus*).

With the Pontian epoch, here classed as Miocene, but by some referred to the Pliocene, a further introduction of mammalian genera was effected.

The plains of Pikermi in Greece, which then stretched far southwards into the area now covered by the Mediterranean, supported large herds of antelopes and gazelles, varying in size and form, and for the most part allied to those of Africa. With these was an animal of intermediate form between the giraffe and antelopes (*Helladotherium*), allied to the short-necked giraffe or okapi recently discovered in Africa. Herds of small wild asses (*Hipparion*), intermediate in structure between *Anchitherium* and the horse, also

TABULAR CORRELATION OF THE EUROPEAN MIOCENE SERIES

	Touraine.	Aquitaine.	Provence and Switzerland.	Austria.	Italy.	Greece.
Pontian.			*Congeria* Beds of Bollene, Loams of Luberon and Cucuron with *Hipparion*.	*Congeria* Beds, 300 feet.	*Congeria* Beds of Tuscany and Lignites of Casino, 200 feet.	Pikermi Beds with *Hipparion*, *Helladotherium*, etc.. Beds with *Congeria*, *Tapes gregaria*, etc.
Sarmatian.			Marls with *Helix Christoli* in Provence.	Marls with *Mactra podolica*, Sands with *Cerithium pictum*, 450 feet.	Marls with *Cerithium pictum*, 60 to 70 feet.	Freshwater marls with *Unio*, etc., Sands with *Mastodon angustidens*.
Helvetian.	Faluns of Anjou and Touraine.	Mollasse of Armagnac, Faluns of Salles, Molasse of Martignas.	Œningben Beds, Marine molasse of Berne, etc.	Limestone of Leitha (Leithakalk), Marls of Baden, Sands of Grund, 150 feet.	Marls of Tortone, Sandy molasse, Superga Beds, 2650 feet.	
Burdigalian.	Sands of the Orleannais and the Sologne.	Faluns of Sancats, Faluns of Léognan, Molasse of Leognan and Pelona.	Muschelsandstein, Gray molasse of Mayence and of Lausanne.	The Schlier, Molasse of Eggenburg, Sands of Horn, etc., 200 feet.	Marls of Langhe, Thick sands, and sandstones, 2000 feet.	

scoured over these plains. Numerous carnivores followed and preyed on the herbivorous animals—large cats and panthers (including *Machærodus*), *Hyæna*, *Ictitherium*, *Hyænictis* (a form intermediate between *Hyæna* and *Ictitherium*).

Stratigraphy

A complete series of Miocene deposits is not to be found nearer than Austria or Italy, but the older Miocenes are well developed in France, and consequently these may be described first.

1. *France*

Basin of the Loire.—The "faluns of Touraine" was taken by Lyell as the type of the Miocene of Western Europe. The name "faluns" is a local agricultural term applied to loose marly or shelly sands which, like the shelly "crag" of Suffolk, were formerly spread over the land for fertilising purposes. The beds occur in scattered patches or tracts over a considerable area of country, extending from the mouth of the Loire to beyond Tours, and also along the banks of the Cher.

Sir C. Lyell describes the faluns as consisting generally of sand and sandy marl full of shells and corals, some entire, others rolled, and others in minute fragments, and the beds are seldom more than 50 feet thick; sometimes, as at Doué, near Saumur, "they form a soft building-stone, chiefly composed of an aggregate of broken shells, bryozoa, corals, and echinoderms, united by a calcareous cement, the whole mass being very like the coralline crag of Suffolk," to be described on a later page.

The fossil contents are those of a shallow but very warm sea. According to Edward Forbes they imply that the beds were accumulated between low-water mark and a depth of 10 fathoms. *Cardita affinis*, *Cardium turonicum*, *Venus clathrata*, and *Voluta Lamberti* occur, with seven species of *Cypræa* and eight of *Conus*, some of them being much larger than any living Mediterranean cowry or cone; species of *Oliva*, *Ancilla*, *Mitra*, *Terebra*, *Pyrula*, *Murex*, *Fasciolaria*, and *Nerita* are present, so that the assemblage is decidedly tropical. The bones of extinct Cetacea are occasionally found together with remains of the terrestrial Mammalia—*Dinotherium*, *Mastodon*, *Rhinoceros*, *Hippopotamus*, and Deer.

Brittany and Normandy.—Small patches of faluns occur still farther north, near the towns of Dinan, Rennes, and in the Cotentin district. M. Dollfus describes the Cotentin faluns as a soft calcareous rock, often entirely composed of rolled organic

debris (crustacea, molluscs, bryozoa, and echinoderms), cemented by a whitish granular paste. Some beds are very hard, others soft and pebbly, with grains of quartz and fragments of the neighbouring rocks; the thickness is not more than 20 feet, and it is known to overlie the local Oligocene limestone. Excepting bryozoa, the fossils which can be identified are few, but the general facies is that of the faluns of the Loire; it is quite possible, however, that the deposit is of somewhat newer date than the more southern Miocene.

Basin of the Gironde.—Near Bordeaux and at several places in the department of the Gironde patches of sandy faluns like those of Touraine overlie the Aquitanien stage of the Oligocene series.[1] There is no continuous section, but the patches have been correlated by their faunas and are believed to occur in the order given on p. 510 in the column headed Aquitaine.

The lowest beds at Léognan contain many fish teeth and echinoderms, and at Pelona a fauna of about 400 species has been obtained, the mollusca including *Ranella tuberosa*, *Tudicla rusticula*, *Strombus Bonelli*, and *Melongena cornuta*. The higher faluns of Léognan yields *Turritella terebralis*, *T.* (*Protoma*) *cathedralis*, *Terebra Basteroti*, etc., and that of Sancats has *Terebra fuscata*, *T. plicaria*, *Cerithium pictum*, *Oliva Basteroti*, and many other shells, some of them preserving their original colours.

In the Helvetian stage are placed the molasse of Martignas, a yellowish sandy clay in which echinoderms (such as *Echinolampas hemisphericus*) are abundant, and the faluns of Salles, which is comparable with that of Touraine and contains *Cardita Jouanneti*, *Pecten solarium*, *Ostrea longirostris* (= *crassissima*), *Voluta Lamberti*, *Cassis saburon*, and *Murex turonensis*.

2. *Belgium*

No deposits quite comparable to those above described have yet been found in Belgium, but near Antwerp the Pliocene sands rest on some dark gray and green sands which have been called the "Black Crag" and appear to be of late Miocene age. They are of small thickness (about 30 feet), but are divisible into two zones or facies :—

Green sand with *Pectunculus pilosus*.
Fine clayey sand with *Panopæa Menardi*.

(1) The sands with *Panopæa Menardi* rest on the Rupelian clay (Oligocene), and have at their base a pebble bed containing rolled blocks of septaria derived from that clay, and often pierced by *Pholas* borings; above are 9 or 10 feet of gray and somewhat

clayey sand full of shells, among which, besides *P. Menardi*, are *Murex Nysti*, *Conus Dujardini*, *Pleurotoma interrupta*, *Astarte radiata*, *Cardita intermedia*, *Venus multilamella*, *Saxicava arctica*, and *Lucina borealis*. (2) Above this are dark glauconitic sands, with *Pectunculus pilosus*, *Ostrea navicularis*, *Pecten Caillaudi*, and some of the same species occurring in the bed below.

3. *Switzerland*

The greater part of the low country lying between the Jura and the Alps consists of Oligocene and Miocene strata. The Oligocene beds described on p. 499 are succeeded by the following groups in ascending order :—

Mayence Group, or Gray Molasse.—Sandstones with remains of terrestrial plants, and including an intercalated marine band with *Murex plicatus*, *Venus clathrata*, *Ostrea crassissima*, and *Cerithium lignitarium*.

Helvetian Group.—At the base are marine sandstones and calcareous conglomerates, with *Conus ventricosus*, *Pectunculus glycimeris*, *Panopæa Faujasi* (=*P. Menardi*), etc., 37 per cent of the species being recent Mediterranean or tropical forms.

Œninghen Beds.—These are of freshwater origin, consisting of sands, marls, and limestones, with seams of lignite.

The Œninghen Beds have yielded an immense number of plant and insect remains to the researches of Professor Heer, who records no less than 500 species of plants, and between 800 and 900 species of insects. The flora contains a mixture of generic forms which are now characteristic of widely separated countries. American forms predominate ; next in number stand modern European genera ; with these are some Asiatic types, and a few *Proteaceæ*, an order which now flourishes in South Africa and Australia. Among insects wood-eating beetles are particularly abundant. With these are remains of fish and freshwater tortoises, a huge salamander (*Andrias Scheuchzeri*), which was taken for a human skeleton when first discovered ; also bones of *Dinotherium giganteum*, *Mastodon tapiroides*, *Palæomeryx eminens* (a ruminant), *Galecynus Œningensis* (a fox having affinities with the civet cat, hares, beavers, and many small carnivores.

4. *Austria*

Miocene strata cover a large area in Austria, and are well developed in the Vienna basin, where they attain a thickness of about 1100 feet and exhibit a complete Miocene succession.

Burdigalian.—The lowest beds are the sands and clays of

Horn, Molt, and Gauderndorf, containing *Ostrea crassissima*, *Turritella turris*, *T.* (*Protoma*) *cathedralis*, and *Potamides plicatum*: above these beds is the molasse of Eggenburg, and still higher a thick deposit of sandy clay known as the Schlier, and containing *Aturia Aturi*, *Pecten denudatus*, *Cryptodon angulatum*, and other shells. The total thickness varies from 200 to over 600 feet.

Helvetian.—At the base of this stage are the sands of Grund with *Tudicla cornuta*, succeeded by the Leithakalk, a massive limestone made up largely of Foraminifera and Nullipores (*Lithothamnion*), and characterised by *Clypeaster altecostatus*, *Pecten latissimus*, *Cassis saburon*, *Ranella marginata*, and reef-building corals, all indicating a warm sea. Elsewhere the limestones are replaced by marls (Badentegel) which contain *Cardita Jouanneti*, *Ancilla glandiformis*, and many species of *Pleurotoma*.

Sarmatian.—This consists of sandstones and sandy clays containing an abundance of shells, but hardly any corals, echinoderms, or bryozoa. The fauna has some affinities with that of the Black Sea, and is believed to indicate a similarity of geographical conditions, namely, a narrow communication with the Mediterranean Sea, and the influx of large rivers producing a diminution in the saltness of the water. At the base are sands with *Cerithium pictum*, about 150 feet thick, and affording a good supply of water to Vienna; above are marly clays (300 feet) with a fauna of more temperate aspect than that of the Helvetian, the commonest shells being *Tapes gregaria*, *Mactra podolica*, and *Buccinum duplicatum*. The flora resembles that of Œninghen, but without the palms.

Pontian or **Congeria Beds.**—These consist mainly of clay, often 300 feet thick, which is the deposit of a large inland sea. The prevalent shells are species of *Congeria*, *C. conglobosa* occurring in the lower part, with *C. triangularis* and *C. rhomboidea* in higher beds, with species of the peculiar Cardiadæ, *Adacna*, and *Monodacna*, like those of the Caspian Sea. These Congeria beds extend eastward through Hungary, Croatia, Roumania, and Southern Russia to the Caspian Sea and Lake Aral, which lakes, together with the Black Sea, may be regarded as remnants of the ancient and much larger Pontian Sea.

5. *Italy and Greece*

It will be seen from the table on p. 510 that Italy also contains a complete succession of Miocene deposits, and that their thickness amounts to nearly 5000 feet. The Burdigalian and Helvetian stages appear to have been formed in a Mediterranean Sea of rather larger extent than the existing Mediterranean, while the

Sarmatian and Pontian beds furnish a record of the gradual contraction of this sea to a large inland sea, cut off from the Atlantic, and apparently also separated from the Pontian Sea by the highlands of Dalmatia and the Balkans.

In Greece no deposits of the older Miocene have yet been found, but beds referable to the Sarmatian and Pontian stages occur at Pikermi in Attica and in the Isle of Samos. The latter have yielded the remarkable fauna described on p. 509. The bones occur in immense numbers in a soft red marly matrix, which hardens on drying. The bones are mostly separate, and some are broken, but many complete limbs occur with the bones in their natural position, as if they had been all washed down together from higher ground during heavy floods.

B. The Pliocene Series

The only parts of Europe where Pliocene deposits attain any great thickness are Italy and Holland. In the former country they reach more than 1000 feet in depth, and were accumulated during a slow subsidence which carried the sea up to the foot of the Apennines; the period closed with subterranean disturbances which resulted in the formation of the later volcanoes (Etna, Vesuvius, and the Phlegræan fields) and in the upheaval of the Italian plains.

In other parts of Europe the Pliocene deposits are of small thickness and extent, and were mostly accumulated in shallow seas not far removed from the existing coast-lines of the Continent. Of these deposits good examples are found in our eastern counties and in Belgium.

The oldest Pliocene deposits in England occur only in Kent and as derived nodules ("boxstones") at the base of the Suffolk crags. The later Pliocenes occupy a considerable area in the eastern parts of Essex, Suffolk, and Norfolk, resting unconformably either on the London Clay or on the Chalk. A small patch has also been discovered in the west of Cornwall.

The English Pliocene has hitherto been generally divided into an older and a newer division, it being supposed that there was a decided break between the Coralline Crag and the Red Crag, both faunally and physically; but recent researches have shown that most of the common fossils of the Coralline Crag occur also in the more southern part of the Red Crag, while it also appears that the higher crags to the north of Aldeburgh are quite as distinct from the Red Crag as that is from the Coralline. Hence the series seems to fall naturally into three groups or stages, which may be tabulated as below:—

Upper	Cromer Forest Bed		about 200 feet.
	Weybourn Crag		
	Chillesford Beds		
	Norwich Crag		
Middle	Red Crag	Butley crag	combined up to 70 feet.
		Newbourn crag	
		Walton crag	
Lower	Coralline Crag		about 70 feet.
	Lenham Beds		thickness unknown.

Life of the Period

Very few of the invertebrate fossils belong to extinct genera, and the majority of the species are either identical with, or only varieties of those now living. Among the vertebrates, however, the majority of the species are extinct, and a few belong to extinct genera, such as *Mastodon*, *Trogontherium*, *Balænodon*, and *Halitherium*. The Pliocene period is distinguished by the appearance of elephants, oxen (*Bovidæ*), true horses (*Equus*), bears (*Ursus*), and wolves (*Canis lupus*), and by the abundance of deer (*Cervidæ*). In France and Italy the Pliocene deposits are characterised by *Mastodon arvernensis*, *Rhinoceros megarhinus*, *R. etruscus*, *Elephas meridionalis*, *Hippopotamus major*, *Cervus cusanus*, *C. perrieri*, *C. pardinensis*, with *Machærodus cultridens*, *Hyæna striata*, bears, and wolves. In England the bed of phosphatic nodules which occurs at the base of both coralline and red crag has yielded the following—*Mastodon arvernensis*, *Rhinoceras incisivus*, *R. Schleiermacheri*, *Hipparion gracile*, *Elephas meridionalis*, *Cervus dicranoceras*, *C. suttonensis*, *Tapirus arvernensis*, *Felis pardoides*, *Hyæna striata*, and *Sus palæochærus*. Other species occur at the base of the Norwich crag.

The following are some of the marine fossils which are characteristic of the several divisions of the Pliocene series in England and Belgium :—

1. *Fossils of the Lenham Beds and Diestian Sands*

Annelida. Ditrupa subulata (ranges to Walton crag).
Bryozoa. Cupularia canariensis.
Brachiopoda. Terebratula grandis.
Lamellibranchia. Arca diluvii, Cardium papillosum, Tellina Benedeni, Gastrana fragilis, Ostrea princeps.
Gastropoda. Conus Dujardini, Terebra acuminata, Triton heptagonum, Pleurotoma consobrina, P. intorta, Pyrula reticulata, Cassis saburon, Murex scalariformis.

2. *Fossils of the Coralline Crag*

Actinozoa. Cryptangia Woodi, Sphenotrochus intermedius (both range to red crag).

Echinoderma. Echinus Woodwardi, Brissus unicolor, Temnechinus Woodi.
Bryozoa. Cupularia porosa, Fascicularia aurantium, Alveolaria semi-ovata, Salicornaria crassa (last three range to Red Crag).

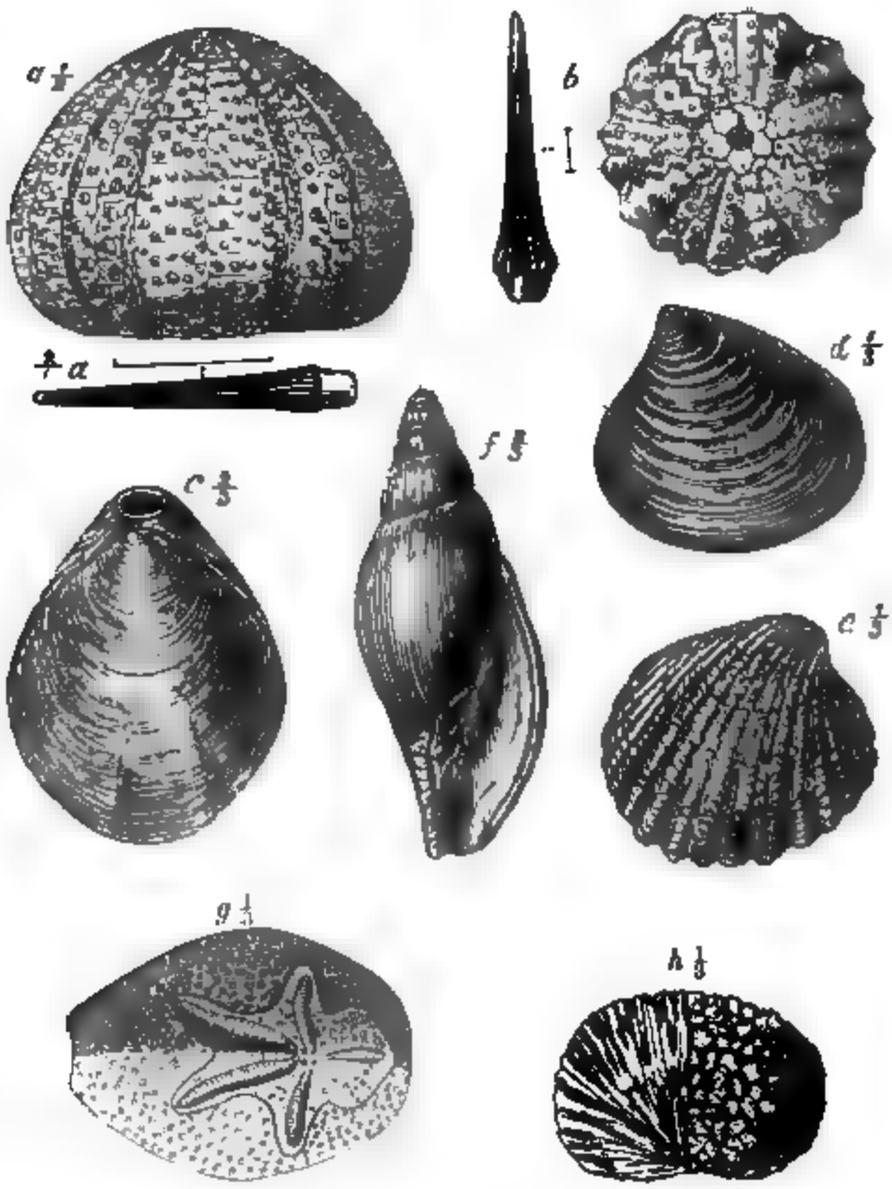

Fig. 168.—GROUP OF CORALLINE CRAG FOSSILS.

a. Echinus Woodwardi.
b. Temnechinus Woodi.
c. Terebratula grandis.
d. Astarte Omalii.
e. Cardita senilis.
f. Voluta Lamberti.
g. Brissus unicolor (=Scilla).
h. Fascicularia aurantium.

Brachiopoda. Terebratula grandis.
Lamellibranchia Astarte mutabilis, A. Omalii, Cardium decorticatum, Cardita senilis, Cyprina rustica, Pecten Gerardi, Isocardia cor (rare in England), Panopæa Faujasi, Limopsis pygmæa.

Gastropoda. Ringicula buccinea, Scalaria clathratula, Trochus Adansoni, Voluta Lamberti, Nassa labiosa (all range into Walton crag).

Besides the above the following are equally common in the Coralline and Red crags—*Astarte Burtini, Mactra arcuata, Pecten opercularis, Pectunculus glycimeris, Venus casina, Cassidaria bicatenata, Buccinopsis Dalei, Trochus Adansoni, Turritella incrassata, Natica millepunctata.*

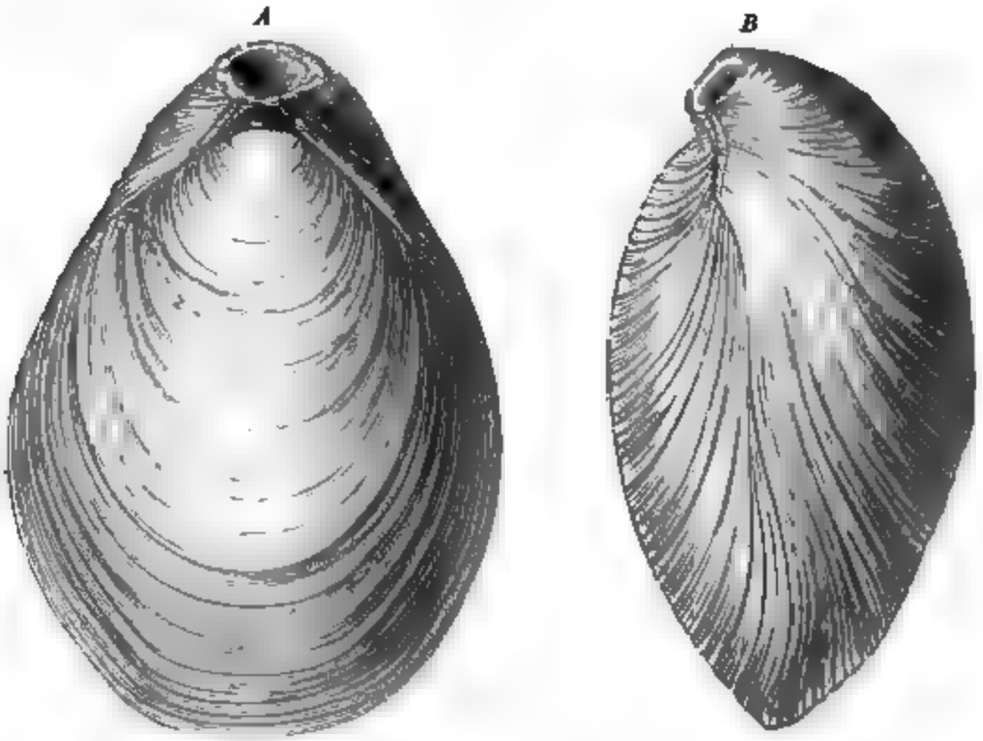

Fig. 109.—TEREBRATULA GRANDIS, A SMALL SPECIMEN OF NATURAL SIZE.
A. Front view. B. Side view.

3. *Fossils of the Red Crag*

Actinozoa. Balanophyllia calyculus.
Echinoderma. Echinocyamus pusillus.
Lamellibranchia. Astarte obliquata, Dosinia exoleta (lentiformis), Cardium Parkinsoni, C. augustatum,† Lucina borealis, Mactra constricta,† M. ovalis,† Tellina obliqua.†
Gastropoda. Nassa reticosa, Neptunea contraria, N. antiqua,† Purpura lapillus, P. tetragona, Columbella sulcata, Natica hemiclausa, Scalaria groenlandica,† Sipho gracilis.
Fish-teeth. Carcharodon megalodon.

4. *Fossils of the Norwich Crag*

Few shells are confined to this division, but some are more abundant in it than in the beds below, and these are principally

† Those which are thus marked are absent or rare in the Walton crag.

such as exist in British seas at the present time. The following are the most characteristic :—

Lamellibranchia. Astarte borealis, A. compressa, Cardium edule, Cyprina islandica, Nuculana oblongoides, Nucula Cobboldiæ, Mya arenaria, M. truncata, Mactra subtruncata, Tellina lata, T. obliqua, T. prætennis, Scrobicularia plana.

Gastropoda. Cerithium tricintum, Conovulus pyramidalis, Littorina littorea, Natica catena, Purpura lapillus, Turritella communis.

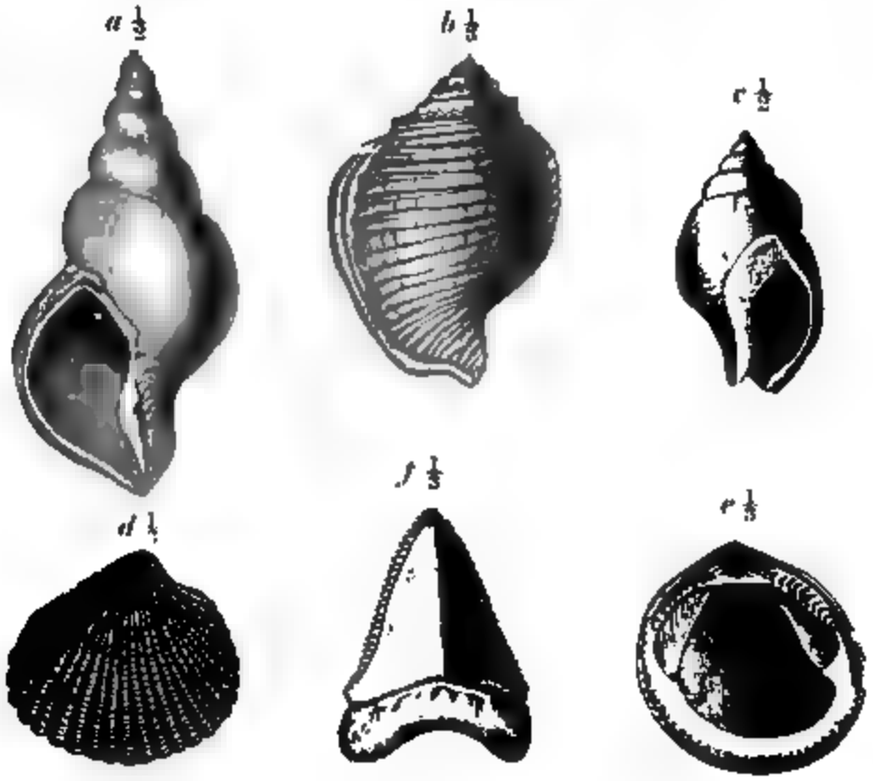

Fig. 170.—GROUP OF RED CRAG FOSSILS.

a. Neptunea contraria.
b. Cassidaria bicatenata.
c. Buccinopsis Dalei.
d. Cardium Parkinsoni.
e. Pectunculus glycimeris.
f. Carcharodon megalodon.

Most of these species occur also in the Chillesford Beds, with the addition of *Cardium grœnlandicum* and *Nuculana lanceolata*, and most of them are found in the Weybourn crag, which latter is specially characterised by the incoming of *Tellina balthica* (= *T. solidula*).

The Norwich crag has also yielded the following mammalia :—*Elephas antiquus*, *Cervus ardeus*, *C. carnutorum*, *Equus stenonis*, *Trogontherium Cuvieri* (an extinct beaver), *Gazella anglica*, *Microtus* (= *Arvicola*) *intermedius*.

5. *Fossils of the Cromer Forest Bed*

Authorities have differed on the question whether these beds should be regarded as the summit of the Pliocene or the base of the Pleistocene, but Messrs. C. Reid, E. T. Newton, and F. W. Harmer agree in classing them as Pliocene, though admitting that they form a passage from one series to the other. The following is a brief review of the flora and fauna.

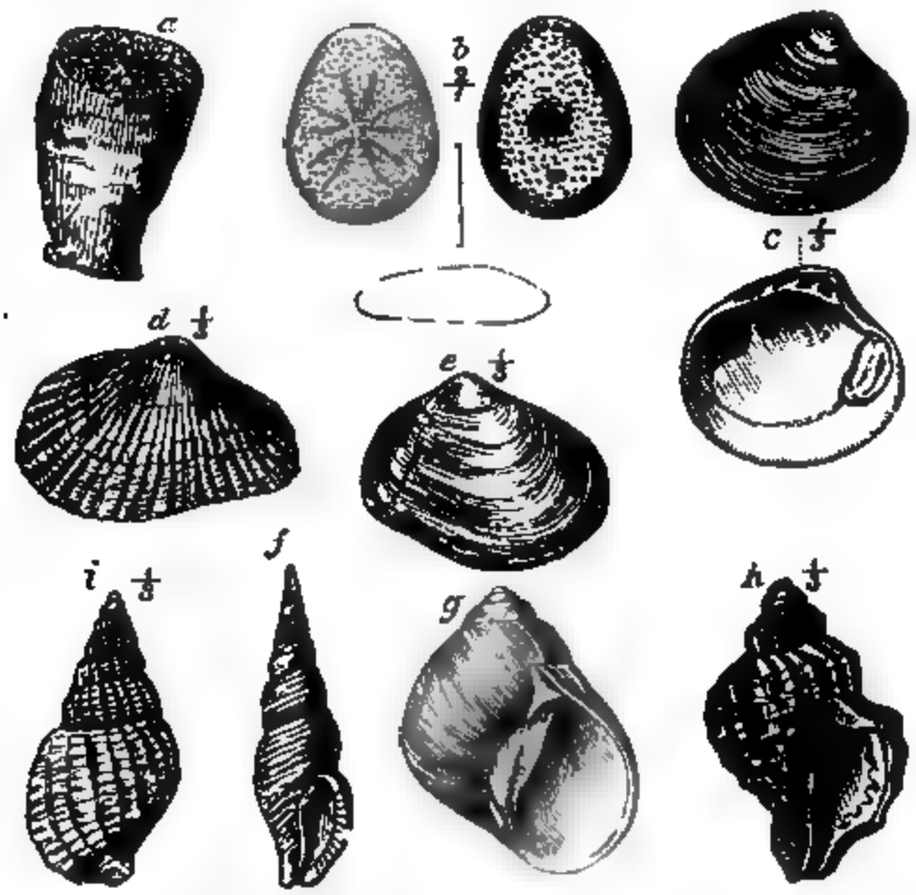

Fig. 171.—FOSSILS OF THE RED AND NORWICH CRAGS.

a. Balanophyllia calyculus.
b. Echinocyamus pusillus.
c. Astarte obliquata.
d. Cardium angustatum.
e. Mactra constricta.
f. Columbella sulcata.
g. Natica hemiclausa.
h. Purpura tetragona.
i. Nassa reticosa.

The flora consists of forest trees and of marsh or aquatic plants, and only two species no longer live in Britain, viz. *Pinus Abies* (the spruce fir) and *Trapa natans* (a pond plant). The assemblage is very similar to that found in Eastern Norfolk at the present day, and Mr. Reid remarks that the occurrence of the maple and the hornbeam shows that the climate cannot have been much, if at all, colder than it is now.

The marine mollusca, of which there are only nineteen species, all occur in the Weybourn Crag, and include some extinct species, such as *Melampus pyramidalis*, *Tellina obliqua*, and *Nucula Cobboldiæ*.

With respect to the land and freshwater mollusca the Norwich crag has yielded twenty-six species, and all of these, except two recent species of *Limnæa* and one of *Pupa*, are also found in the Forest Bed. The latter, however, include many others which do not occur in older beds, and of these some are extinct, *e.g. Viviparus gibbus*, *Limax modioliformis*, *Nematura runtoniana*, and *Pisidium astartoides*, together with some that no longer live in Britain, *e.g. Hydrobia marginata*, *H. Steini*, *Valvata fluviatilis*, and *Corbicula fluminalis*.

The only remaining test of age is that of the mammalia, and when these are arranged in three groups, as below, it is seen that they prove the beds to have been formed just at the epoch of transition from Pliocene to Pleistocene time, a certain number being survivals from the Pliocene (either of Britain or France), and about an equal number being new-comers which range to Pleistocene or to modern times, while a few have not yet been found elsewhere.

(1) *Survivals from Pliocene*, 19

Elephas meridionalis.
,, antiquus.
Rhinoceros etruscus.
,, megarhinus.
Hippopotamus major.
Equus stenonis.
,, caballus (horse).
Ursus arvernensis.
Canis lupus (wolf).
Cervus Sedgwicki.
Cervus poligniacus.
,, Etueriarum.
,, elaphus (stag).
,, verticornis (=C. belgrandi).
Machærodus latidens.
Trogontherium Cuvieri.
Castor fiber (beaver).
Microtus (=Arvicola) intermedius.
Lutra vulgaris (otter).

(2) *New-comers ranging to Newer Beds*, 19

Bison bonasus (var. priscus).
Ovibos moschatus (musk ox).
Ursus spelæus (cave bear).
,, ferox (grizzly bear).
Gulo luscus (glutton).
Canis vulpes (fox).
Mustela martes (marten).
Hyæna crocuta.
Sus scrofa (wild boar).
Myogale moschata (musk shrew).
Sorex vulgaris (shrew).
,, pygmæus (pigmy shrew).
Talpa europæa (mole).
Mus sylvaticus (mouse).
Microtus arvalis (field vole).
,, gregalis.
,, amphibius (water vole)
,, glareolus (red vole).
Sciurus vulgaris ? (squirrel).

(3) *Species not known elsewhere*

Caprovis Savini.
Alces latifrons.
Cervus Savini.
,, Fitchi.
Cervus carnutorum.
,, Dawkinsi.
,, rectus.
,, tetraceros.

Stratigraphy

1. *East of England*

Lenham Beds.—The oldest Pliocene deposits in England are certain patches of ferruginous sand which occur at intervals along the chalk downs of Kent, from the heights above Folkestone to those above Maidstone, most of them being about 600 feet above the sea. They were first described by Professor Prestwich in 1857, and more fully explored by Mr. C. Reid in 1886.[2] The Lenham Beds are mere remnants of a deposit which must originally have had a wide extension not only in England but eastward through Belgium. These remnants have been preserved because they have subsided into deep pipes and hollows caused by the solution of the underlying chalk. The hollows are lined with brown clay full of unworn flints, and these clay walls enclose a set of sandy deposits, yellow and red sands, reddish fossiliferous sandy ironstone, and greenish sand with scattered flint pebbles.

From these beds, and chiefly from the ironstone, Mr. Reid obtained sixty-seven species of mollusca, and all but fifteen have been found in the Coralline Crag, so that there cannot be much difference in their relative age in spite of the great difference in relative level. There are, however, some species which do not occur in the Coralline Crag, but are found in the older Pliocene or later Miocene beds of Europe; these are *Arca diluvii*, *Cardium papillosum*, *Gastrana fragilis*, *Terebra acuminata*, *Pleurotoma consobrina*, *P. Jouanneti*, the first two shells being very abundant. On the whole, therefore, the Lenham Crag is probably older than the Coralline, and Mr. F. W. Harmer thinks that it was considerably older.[3]

Some patches of similar sand occur farther on the Surrey downs, but no recognisable fossils have yet been found in them, and it is consequently uncertain whether they are of the same age.

The nodule bed at the base of the Suffolk crags contains many rounded lumps of tough brownish sandstone which are known as boxstones, and have evidently been derived from an older deposit. Many of these contain fossils, and some of them are species which occur in the Coralline Crag, but two are only known from the older Pliocene of the Continent; these are *Conus Dujardini* and *Voluta auris-leporis*.

Coralline Crag.—This crag is only found over a small area in Suffolk between Aldeburgh and Boyton, and in three other small isolated patches at Sutton, Ramsholt, and Tattingstone (see map, Fig. 172). It rests on an eroded surface of the London Clay,

Fig. 172.—MAP OF THE AREA OCCUPIED BY THE CORALLINE AND RED CRAGS (by F. W. Harmer, from *Quart. Journ. Geol. Soc.* vol. lvi.)

and its basement bed (as seen at Sutton) contains a remarkable assemblage of materials derived from older deposits, and chiefly from the London Clay ; the pebbles are chiefly phosphate nodules of a dark brown colour, but with these are fragments of septaria, a few small pebbles of quartz and flint, and the boxstones which have been mentioned above ; there are also crustacea and fish teeth derived from the London Clay, reptilian vertebræ from the Oxford Clay, mammalian teeth of doubtful age, many Cetacean bones and teeth, and some sharks' teeth which are probably of Pliocene age, such as *Odontaspis hastalis* and *Carcharodon Rondeleti*.

Above the nodule bed there are yellowish marly sands and fine quartz sands, with layers of comminuted shells from 30 to 40 feet thick, and these form the lower portion of the Crag ; above them at Sutton, Gedgrave, and Aldeburgh come about 36 feet of a soft porous yellowish brown calcareous rock, consisting largely of comminuted shells and fragments of Polyzoa, which are often arranged in oblique laminæ, while the bedding is of that irregular kind due to the action of rapid and changeable currents. This soft limestone has probably been formed by the infiltration of carbonate of lime from the overlying Red Crag. Fossils are abundant in both portions.

The mollusca of the Coralline Crag (if they are not drifted) indicate a sea of some depth (40-60 fathoms), and warmer than the neighbouring sea. According to S. V. Wood's summary in 1874 the total number of species was 391, of which 142 were extinct, while 249 are identical with recent forms. Of these living species 205 occur in the Mediterranean, while only 174 occur in British seas, 50 being Mediterranean species which are not British, and 20 British species which are not Mediterranean. Wood has also pointed out "that the most abundant and therefore the most characteristic species of the Coralline Crag are southern species unknown to British seas, and that among the 154 which occur both in British and Mediterranean waters there are many which are really characteristic Mediterranean shells, and are only marked as British in consequence of some rare occurrence."

Red Crag.—Returning now to the eastern counties, we come to the deposit which is generally known as the Red Crag, this name denoting the usual reddish brown colour of the material, which differs considerably from that of the Coralline Crag. The latter (when not decalcified) is a light yellow calcareous deposit consisting chiefly of organic debris with some fine sand, while the Red Crag is a ferruginous shelly sand, its unaltered portions consisting partly of quartz-sand and partly of shells (either perfect or broken), the whole stained by a variable proportion of peroxide of iron (from 5 to 16 per cent)

This formation covers a much larger area than the older (Coralline) crag, and is apparently continuous over a space of about 300 square miles in Suffolk, but is so often concealed by the sands and clays of the Glacial series, that generally it is only on the slopes of the valleys which intersect the district that the crag actually comes to the surface. The best exposures occur in the cliff-sections of Walton-on-Naze, Felixstow, Bawdsey, and in the valleys of the rivers Orwell and Deben.

The Red Crag rests partly on the London Clay and partly on the Coralline Crag, wrapping round the isolated reefs of the latter, and filling up the hollows between them. At its base there is generally a bed of phosphatic nodules with "boxstones" and other derived pebbles, together with rolled bones and teeth of mammalia and of sharks.

From the researches of Mr. S. V. Wood [4] and Mr. F. W. Harmer [5] it appears that the crag in the southern part of this area is decidedly older than that in the northern part. The beds at Walton-on-Naze yield a fauna that Mr. Harmer considers to be closely allied to that of the Coralline Crag, for it includes many southern species and very few of northern origin, while at Butley in the northern part of the area northern species are abundant and southern forms are comparatively rare. Thus it seems as if these red crags were deposited while the sea was gradually retreating northwards, the slowly receding waters leaving a succession of beach and shallow-water deposits behind them. This shelly crag is seldom more than 20 feet deep at any one place, and its bedding is generally oblique, so that it may be described as consisting of a number of shelly sand-banks, each composed of highly inclined laminæ, one bank often being sharply truncated by another.

Mr. Harmer has recently divided the Red Crag into three parts, on the basis of the changing proportion of northern and southern species, and these divisions may be termed the Walton Crag, the Newbourn Crag, and the Butley Crag. The relations of these crags is best expressed by the following table of percentages, in the compilation of which Mr. Harmer has taken into account only the more abundant and characteristic species.

	Extinct Species.	Southern Species.	Northern Species.	Species of Northern and Southern Ranges.
Butley crag . .	13	13	23	47
Newbourn crag .	32	16	11	36
Walton crag .	36	20	5	35
Coralline crag .	38	26	1	3

The Walton Crag is characterised by the abundance of *Neptunea contraria*, *Columbella sulcata*, *Nassa labiosa*, *N. elegans*, *Trochus Adansoni*, *Buccinopsis Dalei*, and *Dosinia exoleta;* the Newbourn Crag by abundance of *Cardium augustatum*, *Mactra ovalis*, *M. constricta*, and *Tellina obliqua;* the Butley Crag by *Neptunea antiqua*, *Buccinum grœnlandicum*, *Cardium grœnlandicum*, *Nucula Cobboldiæ*, *Tellina obliqua*, and *T. prætenuis*.

The manner in which the Red Crag is sometimes banked against the Coralline Crag is illustrated in the section, Fig. 174. In the pits near Sutton there is evidence of two shore-levels, an upper and a lower cliff-line. The upper cliff is about 12 feet high, and must formerly have been higher, as blocks of a hard bed capping the hill above are found at its base, and some of them weigh more than a ton. With these blocks are flints and coprolites and shells of *Mytili*, while the surface of the Coralline Crag is perforated by *Pholas* borings. The lower shore-line is about 9 feet below the upper, and here again derived blocks, coprolites, and *Mytili* were found. These two shore-lines are traceable all round the mass of Coralline Crag intersected by the section, Fig. 174, a mass which evidently formed a reef in the Red Crag sea.

Norwich Crag.—This group has a more extended range than either of the older crags, since it is found more or less continuously through Eastern Suffolk from Aldeburgh to Bungay and Beccles, and thence through Norfolk to Brundall and Norwich (on the river Yare), and to Coltishall and Burgh in the Bure Valley, a distance of about 40 miles. It is well exposed at several localities in the neighbourhood of Norwich, whence it takes its name; it is a variable group of sands, laminated clays, and pebbly gravels, with occasional seams or patches of shells, and different local names were given to different portions of the group before it was ascertained that they all belonged to one division of the crag.

Mr. F. W. Harmer remarks that "the Norwich Crag beds are separated by a considerable interval [of time] from any part of the Red Crag. Their molluscan fauna has a much more recent character; they never exhibit the highly inclined bedding so characteristic of the Red Crag, and they attain a much greater thickness than the latter; they occupy an entirely different area, and appear to have originated under somewhat different conditions."[6]

The Norwich Crag appears to cut off the Coralline Crag abruptly near Aldeburgh (see Fig. 173), and it probably also truncates the Red Crag, for the latter has never been recognised north of that place, while the newer crag thickens northward very rapidly. In a boring at Leiston, only two miles from the border of the Coralline

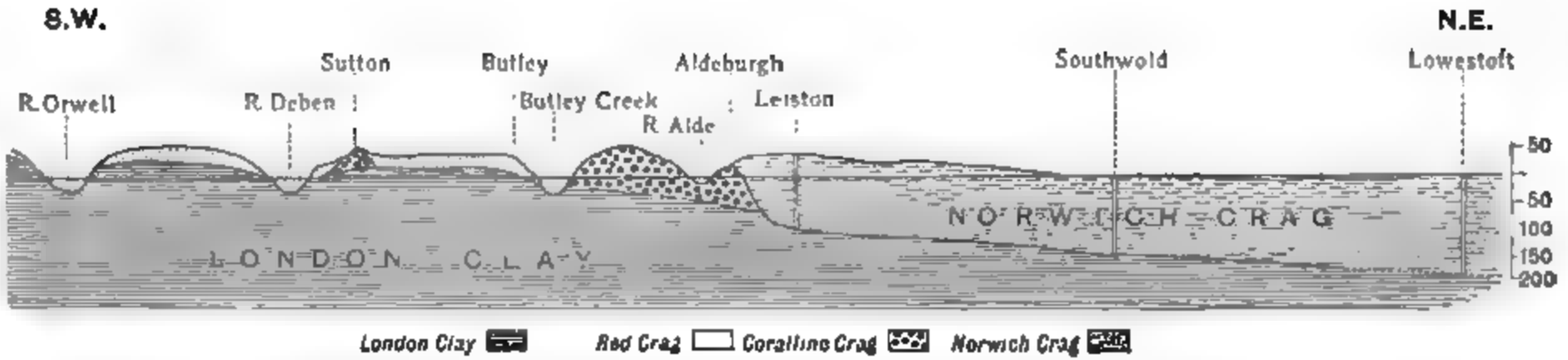

Fig. 178.—SECTION TO SHOW THE RELATIVE POSITIONS AND THICKNESSES OF THE EAST ANGLIAN CRAGS (by F. W. Harmer in *Quart. Journ. Geol. Soc.* vol. lvi. p. 784). Distance about 45 miles.

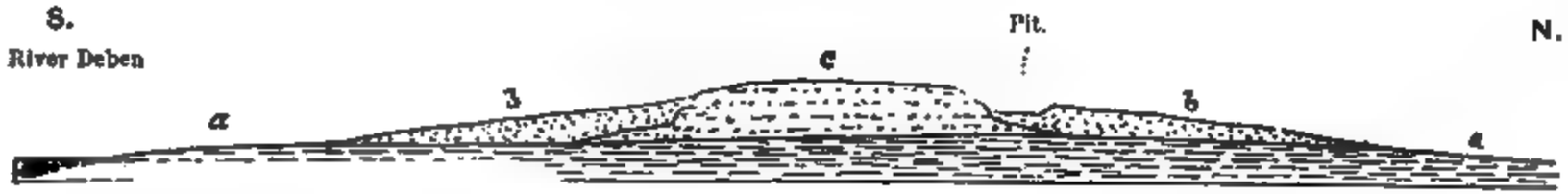

Fig 174.—SECTION THROUGH THE CRAG-PITS NEAR SUTTON (after Professor Prestwich). Distance about half a mile.

c. Coralline Crag. *b*. Red Crag. *a*. London Clay.

Crag, it was found to be 134 feet thick, at Southwold 147 feet, and at Lowestoft 180 feet were traversed without reaching its base.

Norwich Crag is not well exposed in any cliff-section, but a few feet of it are seen at the base of the cliffs near Southwold and Easton Bavent, the succession at the latter place being as follows :—

	Feet.
Glacial Beds—Bedded sands with flint pebbles . . .	up to 7
Chillesford Beds—Bedded sand and clay	,, 12
Norwich Crag—Sand with three layers of shells . . .	,, 4

At Aldeby, on the north side of the river Waveney, a brickyard exposes a similar succession, and about sixty-six species of mollusca have been obtained from the shelly sands. A special feature of this locality is that many of the bivalves occur with united valves in the position of life ; they include *Mya arenaria*, *M. truncata*, *Nuculana oblongoides*, *N. lanceolata*, *Lucina borealis*, *Mactra ovalis*, *Scrobicularia plana*, *Tellina lata*, and *T. obliqua*.

Along the valley of the Waveney this crag is exposed in many pits near Norwich, Bramerton, and Brundall. The beds vary from 15 to 20 feet in thickness, and consist mainly of sand with occasional seams of brown clay, and have generally a bed of rolled flints and pebbles at the base, in which mammalian bones and teeth have been found. Similar crag occurs in the valley of the Bure at Coltishall and at Burgh near Aylsham, the latter being the most northern place to which the Norwich Crag has been traced. The fauna of the beds near Norwich and Coltishall is similar to that farther south, but includes the northern shell *Astarte borealis*. In both areas, land and freshwater shells are sometimes found, such as *Helix hispida*, *Limnæa palustris*, *Viviparus medius*, and *Corbicula fluminalis*.

Chillesford Beds. — There has been much difference of opinion about these beds and their relation to the Norwich Crag. The geological surveyors (Messrs. W. Whitaker and C. Reid [7]) distinguish between Chillesford Crag and Chillesford Clay, regarding the former as part of the Norwich Crag and the latter as a separate and higher horizon. Mr. Harmer agrees with these authors that what has been called Chillesford Crag or Aldeby Beds is in most localities indistinguishable from Norwich Crag, but he differs from them in regard to the sand below the clay at Chillesford, which he regards as belonging to the Chillesford Beds, believing it to be an exceptional bed without a parallel elsewhere. Fig. 175 shows the relations of these beds to the older crags near Aldborough according to Prestwich, but the existence of Red Crag there is doubtful.

The Chillesford Beds consist of finely laminated clay and sand, always micaceous, lying horizontally, and often in alternating layers of clay and sand. They are often from 18 to 20 feet thick ; they rest indifferently on the Coralline, the Red, and the Norwich Crags, and have been traced from Walton-on-Naze to Mundesley in Norfolk, a distance of about 90 miles. Mr. Harmer has pointed out that when the exposures of these beds are plotted on a map they arrange themselves in the form of a sinuous band of gradually increasing width as it is traced northward, a form which suggests that they were formed in the estuarine portion of a large river flowing from north to south, and if this was so, the river was probably a continuation of the Rhine.

Weybourn Crag.—This is only found in the north of Norfolk, and takes its name from Weybourn on the coast near Cromer, where it consists of from 1 to 12 feet of loam and sand, with a band of blue clay in the lower part and a basement bed of unworn

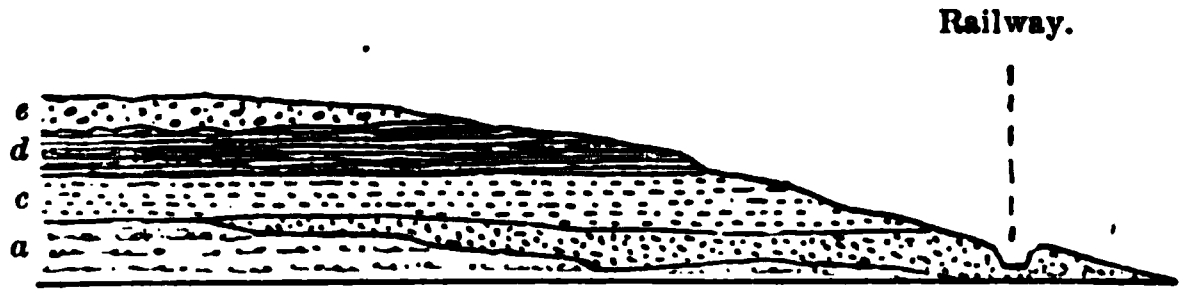

Fig. 175.—DIAGRAM SECTION THROUGH WARREN HOUSE, NORTH OF ALDBOROUGH (PRESTWICH).

e. Pebbly sand (Glacial).
d. Chillesford Clay.
c. Chillesford Sand.
b. Red Crag? (or weathered Coralline Crag).
a. Coralline Crag.

flints resting on the chalk. Its characteristic shell is *Tellina balthica*, which is very abundant, and is a northern species that does not occur in the older crags. Out of fifty-three species of mollusca only five are extinct, and all the rest are such as now live in the North Sea, nine being regarded as Arctic forms, which is a larger proportion than occur in the Norwich Crag. The fauna, therefore, seems to indicate that the Weybourn Crag is newer than the Norwich Crag, and Mr. Harmer believes it to be newer than the Chillesford Beds, for in the Bure valley he distinguishes Norwich Crag overlain by Chillesford Clay, both of which are in places cut through by a pebbly sand which he regards as Weybourn Crag. Mr. Reid is inclined to think that the Chillesford Clay passes laterally into Weybourn Crag, the latter having presumably been formed in shallower water than the former.

Cromer Forest Bed.—The highest member of the Pliocene series is exposed at intervals along the Norfolk coast from Happisburgh to Weybourn. It has been described by many

writers, and was carefully explored for the Geological Survey by Mr. C. Reid, who found the general succession in these cliffs to be as follows :—

			Feet.
Pleistocene	Glacial deposits		
	Leda myalis bed		4 to 15
Pliocene	Upper freshwater bed	Cromer Forest Bed	10 to 20
	Forest bed (estuarine)		
	Lower freshwater bed		
	Weybourn Crag		1 to 12

The lower freshwater bed is a local and discontinuous deposit, its relation to the central estuarine portion resembling that of more recent "submerged forests" to the mud of modern estuaries. The middle division consists of clay, sand, and gravel in irregular layers, and contains a mixture of marine and freshwater shells with many mammalian bones ; it received its name of "Forest bed" from the frequent occurrence of stumps, logs, and matted roots of trees, but these are not in the position of growth, as formerly supposed ; they have all been drifted, though probably not from any great distance, and from the appearances presented by many of the stumps, Mr. Reid concludes that they have grown on the side of a steep river-bank which was continually being undermined and washed away by the current, "and settling generally in an upright position, as we should expect, from the greater density of the roots and from the weight of the adhering soil, they have formed 'snags' in the river, such as are constantly met with in streams flowing through a forest-clad country."

The upper surface of this estuarine deposit is often weathered into a soil and penetrated by small roots (hence termed the Rootlet bed), and is in some places covered by lacustrine deposits containing freshwater shells, with remains of fish, amphibia, and small mammalia ; this is the upper freshwater bed. Among the shells are the following species, *Pisidium amnicum*, *P. astartoides* (extinct), *Corbicula fluminalis*, *Valvata piscinalis*, *V. fluviatilis*, *Viviparus medius*, *V. vivipara*, *Hydrobia marginata*, *Bythinia tentaculata*, and several species of *Helix*.

The *Leda myalis* bed is doubtfully grouped as Pliocene by Mr. Reid, but may with equal convenience be regarded as the local base of the Pleistocene series (see p. 543).

2. *South-West of England*

St. Erth Beds.—At St. Erth, near Hayle in Cornwall, and at an elevation of about 100 feet above the sea, there is an interesting deposit of sand and clay, the latter containing shells which prove

it to be of Pliocene age. A pit near the vicarage exposed the following beds :—

	Feet.
Loamy clay full of angular stones	2 to 6
Fine gravel and coarse ferruginous sand	4 to 6
Clay, yellow above, blue beneath, and containing many fossils	6
Fine foundry sand, base not exposed	?10

The number of mollusca which have been found in the clay is between eighty and ninety, and the greater part of them are such as occur in the lower part of the Red Crag, but many species of a southern character are present, such as *Fusus corneus*, *Nassa recticostata*, *Nassa mutabilis*, *Cardium papillosum*, and *Cardita aculeata*, which do not occur in the eastern crags, while the Boreal and Arctic forms found so abundantly in the higher part of the Red Crag are absent at St. Erth.

Mr. C. Reid has pointed out that the proportion of extinct forms, so far as the fauna has been worked out, is 41 per cent, which exactly corresponds with the proportion in the Coralline Crag; and in view of this and of the preponderance of southern mollusca, he concludes that the St. Erth Beds are of older Pliocene age. Mr. Robert Bell, Professor Kendall, and Mr. Harmer are, however, all opposed to this view, and consider that the St. Erth beds correspond more nearly with the older part of the Red Crag. From the nature of the deposit, from its geographical position, and from the occurrence of beach deposits round St. Agnes Beacon up to 375 feet above the sea-level, Mr. Reid infers that the fossiliferous clay was formed at a depth of 40 or 50 fathoms.

3. *The Pliocene in Belgium and Holland*

In these countries a succession of beds has been described which appears to correspond with the lower and middle portions of the British series, but does not include any representative of the Norwich Crag or of the later Pliocene deposits in England. This succession, as interpreted by the researches of Messrs. Van den Broeck, Dr. Lorié, and Mr. Harmer,[8] is as follows :—

4. Amstelian.
3. Scaldisian or zone of *Neptunea antiqua*.
2. Casterlian or zone of *Isocardia cor*.
1. Diestian or zone of *Terebratula grandis*.

The Diestian sands occupy a position similar to that of the Lenham Beds, and are only found on the high ground along the southern side of the Belgian basin, occupying a considerable

area near Louvain and Diest, but not extending far to the northward.

Near Antwerp are beds which contain a fauna similar to that of our Coralline Crag. At the base is a pebble bed covered by a blackish sand yielding sharks' teeth, *Cyprina rustica*, and *Cardita senilis*, and this passes up into pale greenish gray sand, from which above sixty species of shells have been obtained, the most abundant being *Isocardia cor*, *Astarte Omalii*, *A. corbuloides*, *Lucina borealis*, *Ringicula buccinea*, and *Turritella incrassata*, with bones of *Balæna* and *Balænoptera*. This is generally known as the zone of *Isocardia cor*.

This zone is succeeded by the Scaldisian, which consists of red and gray sands similar to our Red Crag, and containing many of the same shells, especially *Sipho gracilis*, *Neptunea contraria*, *Voluta Lamberti*, *Nassa reticosa*, *N. labiosa*, *Purpura tetragona*, *Pecten maximus*, and *P. Gerardi*. These beds are regarded by Mr. Harmer as the equivalents of the Walton Crag; he points out that *Neptunea contraria* is as abundant as in the English beds, while no specimen of the dextral form *N. antiqua* has been found in the Scaldisian, and he considers the two forms to be distinct species.

No newer beds are found near Antwerp, but borings in Holland, and especially at Utrecht and Amsterdam, have traversed a great thickness of Pliocene, and prove that all the zones thicken greatly toward the north. Thus the Utrecht boring was carried to a depth of 1198 feet without reaching the base of the Pliocene, and this depth is divided as follows by Mr. Harmer:—

		Feet.
Recent and Pleistocene deposits		513
Pliocene	*Amstelian*, yellow sands	262
	Scaldisian, gray glauconitic sands	123
	Casterlian, gray glauconitic sands	300
		1198

Here, therefore, the Pliocene Series is probably at least 700 feet thick. The shells obtained from the Amstelian include *Nucula Cobboldiæ*, *Leda lanceolata*, *Cardium edule*, *Cardium grœnlandicum*, *Tellina prætenuis*, *Mactra subtruncata*, *Mya arenaria*, and *Littorina littorea*, an assemblage which corresponds to that of the later parts of the Red Crag.

No special accounts can here be given of the Pliocene deposits of France and Italy, but the following table shows the chief deposits which have been described in those countries, grouped under the three divisions or stages which are now recognised on the Continent, and with which it would seem that our own Pliocenes can be brought into line.

CORRELATION TABLE OF THE EUROPEAN PLIOCENE SERIES

	England.	Belgium and Holland.	North of France.	South of France.	Italy.
Upper or **Sicilian.**	Cromer Forest Bed. Chillesford Beds, Weybourn Crag, Norwich Crag, 200 feet.	Not recognised.	Ossiferous gravel of St. Prest, near Chartres, with *Elephas meridionalis.*	Sands with *Elephas meridionalis* and *Equus Stenonis,* 50 feet.	Sands with shells of northern species, *Neptunea contraria, Buccinum grænlandicum, Lucina borealis,* and *Mya truncata,* 300 feet.
Middle or **Astian.**	Butley Crag, Newbourn Crag, Walton Crag, † 70 feet.	} Amstelian, Scaldisian.	Marls with *Nassa prismatica.*	Sands with *Mastodon arvernensis,* 150 feet.	Yellow sands with *Pecten latissimus, P. jacobæus, Corbula striata,* and *Cyprina islandica,* 300 feet.
Lower or **Plaisancian.**	Coralline Crag, Lenham Beds, † 100 feet.	Casterlian, Diestian.	Conglomerate with *Terebratula grandis,* Faluns de la Dixmerie.	Marls with *Potamides Basteroti,* Marls with *Nassa semistriata* and *Arca diluvii,* 600 feet.	Blue marls of Plaisantin, etc., with *Nassa semistriata* and *Pecten rimulosus,* 500 feet.

† I have followed the prevailing opinion in grouping the Coralline Crag with the Lenham Beds and in correlating them with the continental Plaisancian, but Mr. Harmer is of opinion that the Coralline should be grouped with the Middle series and not with the Lower or Plaisancian.

Miocene Period.—From the entire absence of Miocene rocks in Britain we may conclude that the whole of the British area was at this time above the level of the sea, and that it formed part of the great Miocene continent which was mentioned on p. 507. There was, in fact, a continuance of the elevation which was in progress during Oligocene times, and the vertical rise appears to have been greater in the west than in the east, thus imparting an easterly inclination to all the Neozoic rocks, and causing the development of the successive escarpments which they now exhibit; it is indeed possible that this easterly dip was greater in Miocene times than it is at present.

The physical features of Central and Southern England appear to date from this period, so far at least as the general contours of the country are concerned. In Oligocene times the courses of the rivers seem to have been very different; the Severn, for instance, may then have been a tributary of the Thames, and the latter could have had no existence as a separate river until the watershed of the Jurassic escarpment had been formed, and its present system of tributaries could only have been developed contemporaneously with the formation of the escarpments; the same may be said of all the streams which run in the longitudinal valleys parallel to these escarpments.

The position of the Lenham Beds on the Kentish downs proves that in early Pliocene time there was little difference in level between the eastern parts of Kent and those of Suffolk, and we may assume that such was also the case in Miocene time though both were above the sea-level of the period.

The North Sea between Britain and Scandinavia must have formed one of the vast plains of the Miocene continent, and was doubtless watered by the rivers which flowed down from the surrounding highlands, and which united perhaps to form the deep trench-like valley which curves round the coast of Sweden, the bottom of which lies 200 feet below the average depth of the North Sea. Over the plain now occupied by this sea and across the English Channel some of the Miocene animals must have roamed into England, but the only evidence of their ever having occupied our islands is the occurrence of the bones of certain species in the nodule beds which form the base of our Pliocene deposits.

Pliocene Period.—The Pliocene deposits of Northern Europe seem to present us with a record of geographical changes which gradually severed the northern sea from any direct connection with the Mediterranean, and finally opened up a channel communicating

with the Arctic Ocean. They also bear testimony to the gradual refrigeration of the climate throughout the whole of the European region.

The geographical conditions of early Pliocene time probably resembled those of the preceding Miocene period more than those of the later Pliocene. There was an eastern or Belgian sea on the site of a Miocene sea, and its waters reached into the eastern part of England ; there is, moreover, every reason to suppose that this sea was connected in some way with a more southern sea, and had no opening toward the north. This is indicated by the large proportion of Mediterranean species among the mollusca of the older Pliocene beds, but it is very difficult to form an opinion as to the direction in which this southern channel lay. Mr. Harmer is of opinion that the Belgian sea was connected with the Atlantic by a channel across the south of England, but between the Kentish downs and the nearest Pliocene deposits to the south-west (in the Cotentin) there is a space of about 170 miles over which no trace of marine Pliocene has been found. Another possible line of communication is by the valley of the Rhine, along which it is probable that there was a connection with the Mediterranean in Miocene time, and although there is here also a gap of 140 miles between Diest and Maintz (Mayence) the intervening ridge is known to have been upraised after the epoch of the Diestian sands.

With respect to the conditions under which the Coralline Crag was accumulated, Mr. Harmer thinks that its materials formed submarine shell-banks piled up under the influence of strong currents from the southward, and that these currents swept up the remains of mollusca and bryozoa from the sea-floor, redepositing them in more sheltered situations. He points out that the shells in the *Isocardia*-sands of Belgium are always in natural position with united valves, while those in our Coralline Crag are for the most part drifted shells, and he regards the deposit as comparable with that of the Turbot bank off the coast of Antrim, which lies below water of 25 to 30 fathoms, and is a shell-bank formed by the tidal current which sweeps through the North Strait.

From the general relations of the newer to the older Pliocene beds we may conclude that the earlier epoch was terminated by movements which probably continued to operate throughout the later part of Pliocene time. From the facts which have been mentioned, especially from the present position of the Lenham beds, from the progressive overlap of the newer crags toward the north, and from the great thickness of the deposits in Holland, we may infer that the movements consisted of an upheaval of the southern border of the older Pliocene or Diestian sea, with either

a contemporaneous or subsequent subsidence of its northern border.

The consequence of the upheaval in the south was to cut off all communication with the seas of more southern latitudes, and to raise the floor of the southern part of the Diestian sea through at least 780 feet. On the other hand the subsidence to the northward allowed the sea to spread farther north than in the earlier part of the period, and before the epoch of the Newbourn and Butley crags it would seem that part of the land which had hitherto united Scotland and Scandinavia was submerged, so that an opening was formed into the Arctic Ocean.

The Red Crag is generally regarded as a shore deposit, and by Mr. Harmer it is compared with the shelly banks and beaches which are now being formed all along the coast of Holland. These accumulations of sand and shells are attributed by Dutch geologists to the prevalence of gales from the west, and as no such shell beds exist now on our eastern coasts this seems to explain the facts, but if such was the origin of the Red Crag, we must suppose that in Pliocene time the prevalent gales were from the eastward, and not from the westward, as is now the case.

As the sea extended its area northward and the land rose on its southern border, the valley of the Rhine must have prolonged itself northward over the southern part of the North Sea plain, and we have seen (p. 529) that the Chillesford Beds may possibly be deposits formed in the estuary of that river. Other indications of a large river flowing from the south present themselves in the Cromer (Forest) beds, and Mr. C. Reid has carefully examined the stones which compose the gravelly portion of the deposit. He found the collection of pebbles to be such that if the river had flowed from the south, west, or north, it must have brought a very different assemblage. "It seems, therefore, that only from the south-east and east could the stones be derived, and that the river must have been very large is shown by the uniformity of the composition of the gravels at considerable distances apart; if this be the correct reading, the river can be no other than the Rhine, a view held by various writers ever since the Forest Bed was first known."

With respect to the change in the climate, the fauna of the Diestian sand and Coralline Crag is that of a rather warm sea, and the mean annual temperature of the surrounding country must have been decidedly higher than it is now in the same latitudes. The subsequent exclusion of the warm southerly current doubtless caused a general diminution of temperature, but there were other meteorologic and cosmic causes which operated in rendering the

climate more and more frigid, till at length in the Weybourn Crag we find a fauna indicative of a climate somewhat colder than that which at present prevails in Norfolk. This prepares us for the great change which took place very soon after the formation of that bed.

References

[1] See a paper on the "Geology of the Gironde," by G. F. Harris in *Geol. Mag.* Dec. 3, vol. vii. p. 22 (1890).

[2] C. Reid on the "Pliocene Deposits of North-Western Europe," *Nature*, vol. xxxiv. p. 341. See also the "Pliocene Deposits of Britain," *Mem. Geol. Survey* (1890).

[3] F. W. Harmer on the "Lenham Beds and the Coralline Crag" in *Quart. Journ. Geol. Soc.* vol. liv. p. 308.

[4] S. V. Wood, *Monograph of the Crag Mollusca*, Pal. Soc. (1872 to 1874, and Supplements 1879 and 1884).

[5] F. W. Harmer in *Quart. Journ. Geol. Soc.* vol. lvi. p. 705 (1900).

[6] In the same paper, p. 737.

[7] W. Whitaker in the "Geology of Southwold," *Mem. Geol. Survey* (1887), and C. Reid, the *Pliocene Deposits of Britain* (1890).

[8] F. W. Harmer on the "Pliocene Deposits of Holland," *Quart. Journ. Geol. Soc.* vol. lii. p. 748, and on the "Crag of Essex (Waltonian)" in *Quart. Journ. Geol. Soc.* vol. lvi. p. 705.

CHAPTER XVIII

NEOGENE SYSTEM (*continued*)

C. PLEISTOCENE SERIES

THE term Pleistocene was used by Lyell to denote the deposits which are newer than the Pliocene, and yet not modern enough to be called Recent. But different writers have different ideas as to what deposits should be called Recent. It seems best to consider the Pleistocene period as including all deposits in this country which are older than the Roman occupation.

Some of these deposits have obviously been formed during a time when the climate became so cold that the higher parts of the country were covered with ice and snow, and the North Sea was more or less filled with ice. Such deposits are called Glacial, and the time during which they were formed is known as the Glacial period, or epoch, and sometimes as the "Great Ice Age," while all the subsequent deposits can be classed as "Post-Glacial." This, however, is not a satisfactory division of Pleistocene time, for as Professor Boyd Dawkins has pointed out, the Glacial epoch must be regarded as a special episode or phase of Pleistocene time, the influence of which was limited to certain parts of the earth's surface; he has shown also that the transition from Pliocene to Pleistocene time is marked by a change in the mammalian fauna of Europe, and consequently that it is the introduction of this fauna, and not the first commencement of Glacial conditions, which marks the beginning of Pleistocene time. These Glacial conditions only modified the range of certain species, limiting that of the southern, and extending that of the northern forms during their continuance.

No general classification of Pleistocene deposits has yet been framed that is applicable to more than one limited region, such as Scotland, or Wales and the Welsh borders; still less is it possible to correlate the Glacial deposits of these regions with the coastal

and fluviatile deposits of a region where there has been no actual glaciation, such as the south of England or the north of France.

For descriptive purposes the principal Pleistocene deposits of the British Isles may be considered under the heads of Glacial and Non-Glacial, and if these are placed in parallel columns a portion of the one set may be regarded as contemporaneous with a portion of the other, though it will be unsafe to assume that any member of one series is contemporaneous with any particular member of the other series. The two series include the following :—

Glacial Deposits	*Non-Glacial Deposits*
...	Alluvial deposits.
4. Latest marine boulder-clays.	Later river gravels, etc. (Neolithic).
3. Moraines, kames, and eskers.	Older river gravels (Palæolithic)
	Cave-deposits and Raised beaches.
2. Later boulder-clays with stratified sands and gravels.	
1. Older and basal boulder-clays.	

Life of the Period

Fossils of the Glacial Deposits

The Glacial deposits contain but very few traces of life, though remains of the mammoth (*Elephas primigenius*) and the reindeer (*Rangifer tarandus*) have been found in the so-called inter-glacial beds of Scotland, while *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus amphibius*, and *Hyæna crocuta* have been found in beds which lie at the base of the boulder-clays on the coast of Yorkshire.

The mollusca of Pleistocene times all belong to living species, but those found in the marine Glacial deposits are such as live in the seas round the northern parts of our islands, the species of our southern coasts being generally absent. The following are some of the commoner species in Glacial beds :—

Gastropoda. Natica clausa, Trophon clathratus, Buccinum undatum, B. grœnlandicum, Pleurotoma (Bela) turricula, Turritella communis, Scalaria grœnlandica.

Lamellibranchia. Pecten islandicus, Nuculana truncata, N. lanceolata, Tellina lata, T. balthica, Astarte borealis, A. compressa, Panopæa norvegica, Saxicava rugosa, Cyprina islandica, Mya truncata.

Fauna of the Palæolithic Deposits

The mammalian fauna of the Pleistocene period is principally known from the remains preserved in the caves and river gravels

of Southern and Central England, some of which are probably contemporaneous with the later Glacial deposits of the more northern districts; there is, at any rate, little doubt that the fauna of the older river gravels is that which existed on the European continent during the Glacial epoch.

This fauna includes a remarkable mixture of species, some being such as would live in a warmer climate than that of

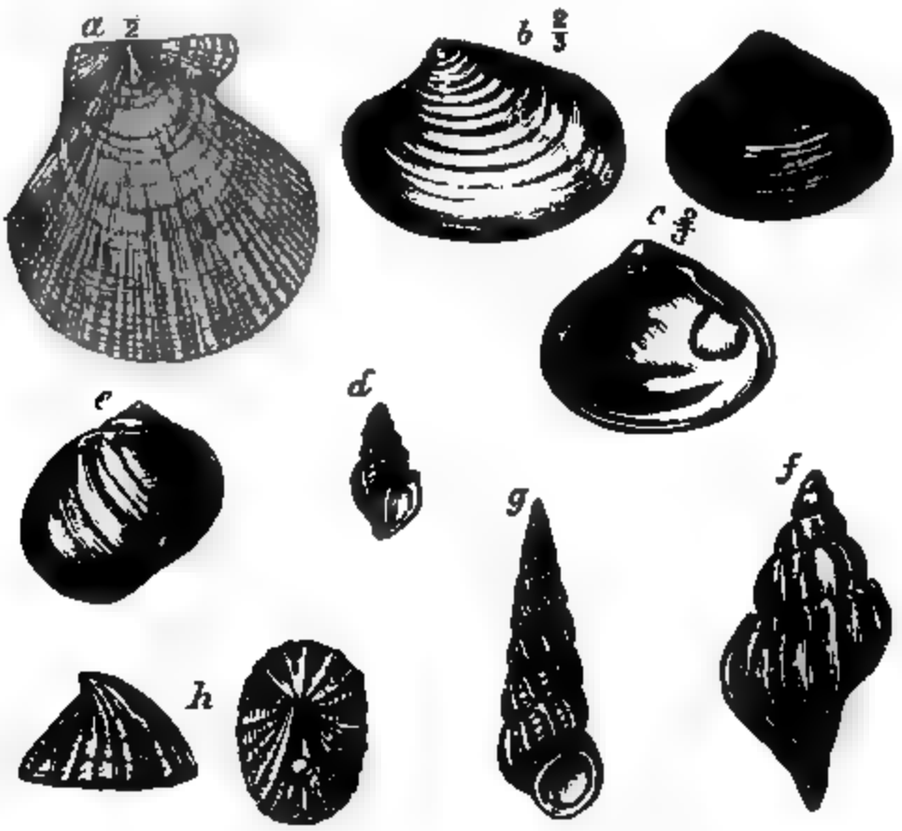

Fig. 176.—GROUP OF PLEISTOCENE SHELLS.

a. Pecten islandicus.
b. Astarte borealis.
c. Corbicula fluminalis.
d. Fusus Fabricii.
e. Natica clausa.
f. Trophon clathratus.
g. Scalaria groenlandica.
h. Puncturella noachina.

modern England (as the lion, leopard, caffer cat, hyæna, lynx, and hippopotamus), while others are northern and Arctic animals (such as the glutton, Arctic fox, musk ox, reindeer, and lemmings). There is also a considerable proportion of extinct species, such as the mammoth and *Elephas antiquus*, three species of rhinoceros, and the Irish elk (*Cervus giganteus = megaceros*).

The following is a list of the mammalia found in the older deposits of the Thames valley and in the lower cave-earths of various caverns:—

(1) *Survivals from later Pliocene*

Hippopotamus major.
Rhinoceros megarhinus.
Elephas antiquus.
,, primigenius.
Bison priscus (bison).
Ovibos moschatus (musk ox).
Machærodus latidens.
Ursus ferox (grizzly bear).
,, spelæus (cave bear).
Gulo luscus (glutton).
Lutra vulgaris (otter).
Hyæna crocuta (spotted hyæna).
Cervus elaphus (stag).
Equus caballus (horse).
Sus scrofa (wild boar).
Canis lupus (wolf).
,, vulpes (fox).
Mustela martes (marten).
Castor europæus (beaver).
Mus sylvaticus (mouse).
Microtus amphibia (vole).
,, gregalis.
,, arvalis.
,, glareolus.
Sorex vulgaris (shrew).

(2) *New-comers in the older Thames Gravels*

Rhinoceros tichorhinus.
,, leptorhinus.
Bos primigenius.
Spermophilus erythrogenoides.
Ursus arctos (brown bear).
Felis leo (lion).
,, lynx (lynx).
,, pardus (leopard).
,, caffer (caffer cat).
Mustela putorius (stoat).
,, vulgaris (weasel).
Canis lagopus (Arctic fox).
Meles taxus (badger).
Felis catus (wild cat).
Cervus giganteus (Irish elk).
,, dama (fallow deer).
Capreolus caprea (roe deer).
Rangifer tarandus (reindeer).
Saiga tartarica (Saiga antelope).
Myodes torquatus (Norway lemming).
,, lemmus (Arctic lemming).
Lepus variabilis (mountain hare).
Lagomys pusillus (tailless hare).
Microtus ratticeps (Russian vole).

Fauna of the Neolithic Deposits

The Neolithic fauna is very different from the above, and includes only one extinct species (*Cervus giganteus*), though there are of course many animals which have subsequently become extinct in Britain, such as the reindeer, brown bear, wolf, wild boar, and beaver. Palæolithic man was a hunter only; Neolithic man was a herdsman and agriculturist, and he introduced several domesticated animals, such as the dog, sheep, goat, pig, and short-horn cow. The stone weapons of Palæolithic man are roughly and broadly chipped, while those of Neolithic man are minutely worked and more carefully shaped and finished, the stone axes being often partly or wholly ground to a cutting-edge.

The Glacial Deposits

It will be convenient to describe the Glacial deposits first, as they are more considerable both in thickness and in extent.

Nature of Deposits.—What are known as Glacial deposits or Glacial drifts are the relics of a period when the conditions

which are now confined to the Arctic and Antarctic regions prevailed over the whole of Northern Europe. The deposits accumulated during this period are principally such as result from the action of moving masses of ice (boulder-clays), or from the action of strong currents of water (coarse gravels), but interstratified with these there are sometimes sands, brick-earths, and laminated loams which have been deposited in quiet water and in a more gentle manner.

The chief product of the Glacial epoch is the material known as boulder-clay. There are several varieties of such clay, and it is by no means certain that they have all been formed in the same manner. It is generally believed that the stiffer, more compacted, and unstratified masses of boulder-clay are the product of land ice, though exactly how a continuous sheet of such material can have been accumulated *under an ice-sheet* has never been satisfactorily explained ; it is, however, fairly certain that such materials were gathered and transported by land ice. Other boulder-clays are of a looser texture, and are frequently associated with stratified sands and gravels which contain marine shells, and such clays must either be marine boulder-clays formed where ice invaded the sea, or the materials must have been ploughed out of a sea-floor by an ice-sheet and spread out on the land beyond.

Glaciation of Rock-Surfaces.—In nearly all districts where boulder-clays occur the rock-surfaces which underlie the lowest clays are glaciated, that is to say, they are grooved, scratched, and smoothed as they would be by the passage over them of heavy ice, which, when its sole is full of stones and boulders, becomes a gigantic rasping, graving, and moulding tool. In most cases it is found that the grooves run parallel to the main valleys of a district, and in many cases when the directions are marked on a map it is seen that they radiate outward in all directions from some central mountain tract ; but occasionally they run in one direction across some tract of country without any reference to its valley system, as if the ice had been locally deflected from its natural course. This system of grooves and striations is often called the glaciation of a district or country.

Stratigraphy

The Glacial deposits are spread over large tracts of the British Islands, and are found in all parts except the extreme south of England and Ireland ; but they differ so much in different districts, and vary so much even in different parts of the same general district, that few writers have yet attempted anything like a general correlation of them. Our knowledge of them is not yet sufficiently

complete for any such attempt to prove satisfactory, and at present, therefore, most districts have each their own local classification and nomenclature. Consequently, it seems best to select for description a few parts of the British Isles where the glacial deposits are well exposed, and where they have been fully described. Thus some account will be given of the following districts:—

1. East Anglia.
2. Lincolnshire and Yorkshire.
3. North Wales and Cheshire.
4. Northern England.
5. Central Scotland.
6. Northern Ireland.

1. *East Anglia*

In the east of Norfolk and Suffolk, where the most complete sections of the Lower Glacial beds are found along the coast, the following succession of deposits can be recognised, but there is no place where they can all be seen in vertical succession:—

Upper group	Plateau gravels.
	Chalky Boulder-clay.
Lower group	Contorted Drift (loams and sands).
	Brown Boulder-clay (Cromer Till).
	Arctic plant bed and *Leda myalis* bed.

Above the Cromer freshwater beds and below the Glacial deposits there are two discontinuous beds which appear to be the oldest Pleistocene beds in Norfolk.

The *Leda myalis bed* is only found between Old Hythe and Cromer, for south of Cromer it either thins out or is cut off by the boulder-clay. The bed consists of fine current-bedded loamy sand, with thin seams of loam and gravel. The fossils are marine, and indicate a depth of 5 or 10 fathoms, as some of the bivalves occur with the valves united in the position of life. All the mollusca yet found (nineteen species) belong to living species, and they include two characteristic crag shells, *Neptunea antiqua* and *Tellina obliqua*. One of the best exposures is at Runton Gap, near Cromer, where *Leda myalis*, *Mya arenaria*, and *Astarte borealis* may be found in position of life, and the bed is 15 feet thick.

The *Arctic freshwater bed* was first described in 1880[1] by Mr. C. Reid, who then distinguished it from the Forest Bed, and placed it in the Pleistocene series, because the plants it contains indicate a great change from the climate of the earlier bed. Trees seem to have entirely disappeared, and the plants include the dwarf Arctic birch (*Betula nana*), the Arctic willow (*Salix polaris*), and mosses which now only live within the Arctic circle. It consists of a layer of clay and loam about two feet thick, but is not by any means continuous, having only at present been found at three

localities on the coast, viz. Beeston, Mundesley, and Ostend, near Bacton. At Mundesley it has yielded freshwater shells, elytra of beetles, and bones of *Spermophilus* (a squirrel-like creature).

The *Cromer Till*, where thickest near Happisburgh, consists of two beds of tough gray unstratified boulder-clay, with an intermediate band of finely laminated and ripple-marked clay. The boulder-clays contain fragments of marine shells, with pebbles and boulders of many kinds of rocks, including gneiss, mica-schist, carboniferous limestone, basalt, red and gray granites, and "rhombyn-porphyr" from Norway, with pebbles of hard chalk which have been bored by marine annelids, and subsequently striated.

The *Contorted Drift* is usually a yellowish marly and sandy clay full of stones, so that it is really only a variety of boulder-clay, but it exhibits a rude kind of stratification, and includes knots, patches, and seams of sand and gravel, and the whole has a twisted, contorted, and kneaded appearance. Another remarkable feature of the deposit is the occurrence of large tabular masses of chalk, some of which are 20 to 30 feet thick, and from 100 to 180 yards long. This drift contains boulders similar to those in the till below and many broken shells, the latter being frequent in the nests and patches of sand, *Tellina balthica*, *Cardium edule*, *Cyprina islandica*, and *Mya arenaria* being the commonest species.

Near Cromer the thickness of the Contorted Drift is sometimes as much as 170 feet, and the contortions are very marked, but south-eastward the deposit passes into a tolerably regular bed of stony loam about 30 feet thick, intercalated between two thick beds of sand, each from 20 to 40 feet thick, the upper of which contains the same marine shells as are found in the contorted masses near Cromer. The same change into loams, sands, and fine gravels seems to occur as the Contorted Drift is traced to the south-west beneath the Upper Glacial clay (see Fig. 177). Moreover, the underlying Cromer Till appears to thin out, so that in the neighbourhood of Norwich the Lower Glacial group consists only of the two following members :—

Stratified sands and gravel, 10 to 20 feet.
Brown stony loam and boulder-clay, 10 to 30 feet.

Such beds, with occasional intercalations of laminated loam or brick-earth, cover large areas in the east of Norfolk, Suffolk, and Essex, but as the beds are followed to the higher ground in the western parts of these counties, and to the chalk escarpment in Cambridgeshire, they thin out and are overlapped by the Upper Glacial clay, which then rests directly on the chalk.

The Chalky Boulder-Clay is a stiff bluish gray clay, con-

taining an abundance of ground-up chalk and striated chalk-stones, together with flints and a variety of other rocks; among these the debris of Jurassic rocks is conspicuous, the great clay formations —Lias, Oxford, and Kimeridge clays—have evidently furnished much of the clayey material, for septaria from these clays and pieces of limestone, like the Lincolnshire oolites, are very numerous, and derived fossils, such as *Gryphæa arcuata*, *Gryphæa dilatata*, *Cardinia Listeri*, etc., and *Belemnites abbreviatus*, are not uncommon. In this respect it contrasts with the boulder-clays of the Lower Glacial group.

This boulder-clay exhibits a fairly uniform character over a large area, and spreads over a part of South Norfolk, Suffolk, Essex, Cambridge, Herts, and Middlesex, the most southerly outlier being that on Muswell Hill, north of Highgate; here the clay is of the usual pale colour, and contains occasional fragments of red chalk, which must have journeyed a distance of some 100 miles for the nearest place whence they could have been derived is Hunstanton in Norfolk.

Another fact of some importance in connection with the formation of this clay is the occurrence in it of pebbles which have been carried up to a level much higher than that of their source; thus phosphatic nodules derived from the Cambridge Greensand have been found at a level of 500 feet above the sea, whereas the outcrop of the parent stratum to the north and west is everywhere under 150 feet.

The thickness of this great sheet of boulder-clay is very variable, sometimes only a few feet can be seen, and in other places borings have gone through 100 or 150 feet of it. Its base-line is very irregular, and it sometimes descends with a rapid slope into valley-like troughs, which are thus completely filled with the clay.

Plateau Gravel.—The last and highest Glacial deposit in East Anglia is a coarse flint gravel which forms isolated plateaux, such as Mousehold Heath, near Norwich, and consists mainly of large rolled and battered flints with some pebbles of quartz, quartzite, granite, etc. This gravel attains a thickness of from 20 to 40 feet; it generally rests on the upper boulder-clay, and seldom, if ever, reposes directly on the chalk.

2. *Lincolnshire and Yorkshire*

The Glacial deposits of these counties deserve attention because they have been fully described and much discussed, although they present many difficulties, and no agreement has yet been arrived at with regard to the relative ages of the deposits which occur on the

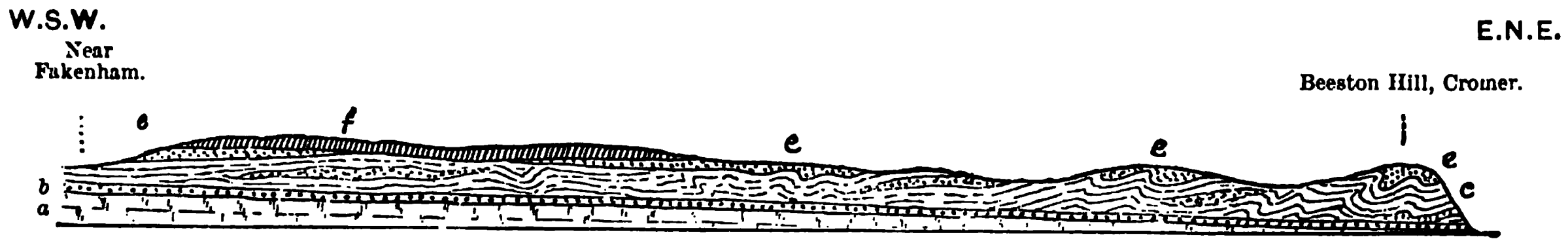

Fig. 177.—DIAGRAM SECTION FROM FAKENHAM TO NEAR CROMER IN NORFOLK. Distance about 18 miles.

f. Chalky boulder-clay.
e. Sand and gravel.
c. Contorted Drift and Cromer Till.
b. Norwich and Weyborne Crags.
a. Upper Chalk.

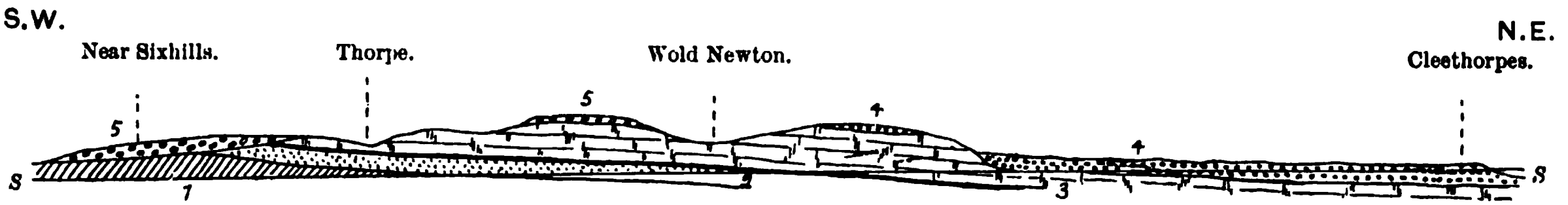

Fig. 178.—SECTION THROUGH PART OF EAST LINCOLNSHIRE (after Searles Wood). Distance about 17 miles.

S.S. Sea-level.
5. Chalky boulder-clay.
4. Hessle and Purple clays.
3. Upper Cretaceous rocks (chalk).
2. Lower Cretaceous rocks.
1. Kimeridge Clay (Jurassic).

eastern and western sides of the Chalk Wolds. The boulder-clays found on the one side of this ridge differ greatly from those on the other side, and no exposure has yet been found which shows the two in apposition. We shall therefore give a brief description of the two types, and will afterwards indicate the views which have been expressed about them.

The Western Type.—There can be no doubt that the mass of the boulder-clay which is found to the west of the Chalk Wolds is the same as the Chalky Boulder-Clay of East Anglia and the eastern Midlands. It can be followed from Cambridgeshire through the counties of Huntingdon, Northampton, and Rutland into South Lincolnshire, and it appears to have formed a continuous sheet or mantle which covered even the summit ridges of the Jurassic escarpment. Near this escarpment Jurassic debris decidedly preponderates over chalk debris, and we again meet with the phenomenon of stones being carried up far above their parent sites. The boulder-clay of the high ground between Stamford and Grantham is also remarkable for containing huge masses of Lias Marlstone and Lincolnshire Limestone, which have been carried many miles from the spots whence they were quarried by the ice. These blocks appear to have come from the west and north-west. Carboniferous rocks have also come from the north-west, and chalk from the north-east, so that several ice-currents seem to have met in this area.

The same boulder-clay is also found in the central parts of Lincolnshire, spreading over the Jurassic clays east of Lincoln by Tattershall, Horncastle, Wragby, and Market Rasen; and the increase in the amount of chalky matter in the direction of the Chalk Wolds is particularly noticeable, till near these hills it becomes a stony chalk-marl, and has been burnt for lime in some places. There is, however, very little of it on the Wolds themselves, though its occurrence at Kelstern, near Louth, proves that it originally spread over all levels below 400 feet.

Below the escarpment it has been traced northward to Brigg, but has not yet been identified at any place farther north in this direction, though it is probable that the lower gray boulder-clay of the vale of York was part of the same sheet.

The Eastern Type.—The boulder-clays of the eastern districts are generally of a purplish or reddish brown. In Lincolnshire they occupy the tract which lies between the eastern slopes of the Wolds and the marshes which border the coast; in Yorkshire they occupy the area which holds a similar position, and is known as Holderness (see map, Fig. 140). They occur chiefly at low levels, but enter the valleys of the Wolds, and in Lincolnshire

appear to have mantled their slopes up to a height of at least 380 feet; beyond Holderness they occur on the chalk to a height of 440 feet, and descend into the Vale of Pickering, forming the cliffs as far as Filey, and occurring at intervals along the coast to the northward.

An important fact is that these clays with associated sands and gravels are banked up against an ancient coast-line which in places presents the form of a buried line of cliffs. Such cliffs appear to exist in Lincolnshire from Welton near Burgh to Hawerby, about 8 miles north of Louth. They occur again in Yorkshire, and are intersected by the present coast-line at Sewerby.

In Lincolnshire the basement beds are now here visible, but it is known from borings that they are from 60 to 100 feet thick, and that they rest on a floor or scar of chalk which is about 80 feet below the present sea-level, where it passes under the sea The base of the series is nowhere visible, but borings prove that there is always a basement bed of chalk-rubble from 2 to 8 feet thick. The clays which are visible are of two kinds, (1) a lower clay of a purplish brown colour (the "Purple Clay"), containing stones and boulders both large and small; (2) an upper clay of a dull red colour mottled with ashen gray, containing many small stones, pellets of chalk, and bits of coal, but few large boulders; this is known as the "Hessle Clay."[2]

Near the border of the Wolds patches of sand and gravel are frequent, often resembling beach deposits, and containing many marine shells, some of which are perfect, but most are broken. They include *Mya truncata*, *Corbula gibba*, *Mactra subtruncata*, *Tellina balthica*, *T. lata*, *Cardium edule*, *Cyprina islandica*, *Venus gallina*, and (at Croxton) *Corbicula fluminalis*, which is also abundant at Kelsey in Yorkshire. At Kirmington, and about 80 feet above sea-level, an interesting deposit of laminated silt or warp occurs containing Foraminifera, *Rissoa ulvæ*, *Scrobicularia plana*, and other bivalves; it resembles the warp formed between tide-marks on the present coast, and is overlain by 10 or 12 feet of beach shingle. The occurrence of such undisturbed marine silt in association with the boulder-clays and marine gravels is of much importance.

In Holderness the sea has cut back into the Glacial deposits, and good sections are thus exposed in the cliffs, especially at Dimlington, Bridlington, and Sewerby.[3] The succession of beds seen at these places is as follows, the total thickness being from 60 to 100 feet:—

5. The Sewerby gravels.
4. The Hessle boulder-clay.
3. The Purple boulder-clay.
2. The Basement boulder-clay.
1. Chalky gravel and buried cliff beds.

The chalky gravel appears to form a nearly continuous basal bed. The buried cliff beds are only seen at Sewerby, where they are banked against the ancient coast-line above mentioned. The section here is represented in Fig. 179, and the mammalian bones mentioned on p. 539 were found in the old beach and in the overlying rainwash.

The Basement clay is of a greenish gray colour, is sometimes 30 feet thick, and includes twisted layers or patches of sand which contain marine shells; no fewer than 110 species have been found, and among them are some which no longer live in British waters, such as *Nuculæ Cobboldiæ*, *Tellina obliqua*, *Astarte borealis*, *Fusus spitzbergensis*, and *F. Sarsi*.

The Purple and the Hessle boulder-clays have the same characters as in Lincolnshire. The commonest stones in these and the lower

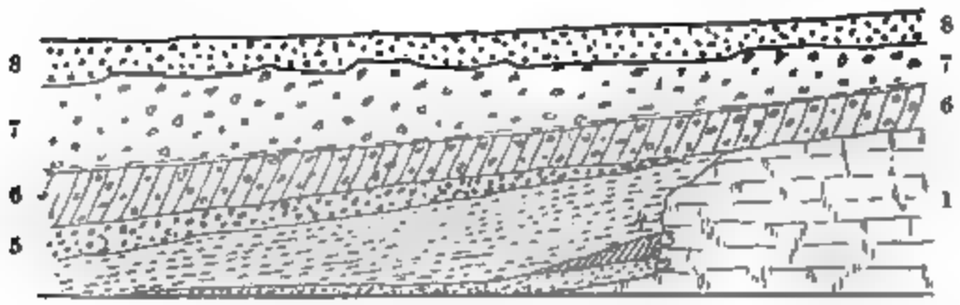

Fig. 179.—CLIFF SECTION AT SEWERBY (after G. W. Lamplugh).

8. Sewerby gravel.
7. Purple boulder-clay.
6. Basement boulder-clay.
5. Chalky gravel.
4. Blown sand
3. Rainwash
2. Pebble beach
} Buried cliff beds.
1. Chalk.

clay have been derived from the Carboniferous rocks to the northward, but some have come from the Cheviot Hills, others from Teesdale and from Cumberland, while a few are identical with rocks in the south and west of Norway.

Relative Age.—The correlation of the beds above described with those of more southern counties, and the relation of the eastern to the western deposits, are debated questions, but two opinions have been expressed, and a third view is also possible. (1) The eastern series may be newer than the western (Chalky Boulder-clay), and therefore later than any deposit in East Anglia (except the plateau gravel); (2) the eastern series may be the older of the two and equivalent to the Lower Glacial of Norfolk; (3) the eastern and western clays may be of nearly the same age, but formed by different ice-streams, the one coming from the north and north-east, the other from the north-west.

The first of these is the older view, and is supported by the fact that the western clays appear to have undergone more subsequent erosion and destruction than the eastern, and also by the entire absence of chalky clay above the latter, for if the second view were correct it is difficult to explain the non-occurrence of such a superposition in some part of Holderness. There are some facts, however, which favour the second view, for there is much general similarity between the drifts of Holderness and those of Cromer; further, when the latter are followed along the north coast of Norfolk, part of them seems to pass into beds which have all the characters of the Hessle clay.

3. *North Wales, Cheshire, and West Lancashire*

Glaciation.—The glaciation of the country, or the manner in which the more exposed rock surfaces have been grooved and striated by the passage of ice, may first occupy our attention. Sir A. Ramsay has shown that among the Welsh mountains the direction of these markings corresponds to the general trend of the larger valleys, and that they must be attributed to the action of glaciers. This is especially noticeable in those valleys which radiate from the Snowdonian mountains to the southward, eastward, and northward.[4] In Anglesey, however, the glacial striæ run from north-east to south-west at right angles to the trend of the great valleys which open on to the Menai Straits, and it is clear, therefore, that the glaciation of that island is not due to the local glaciers. Again, in Flint and Denbigh the striæ run across and not down the valleys, except that of the Dee, which roughly coincides with their general direction, this being from W.S.W. to E.N.E. Lastly, in Cheshire and the south-west of Lancashire the prevalent direction is from N.N.W. to S.S.E. From these facts it is clear that a large body of ice came from the north and passed southward on each side of Wales, the local ice being deflected by it.

Glacial Deposits.—The observations of Mr. Mellard Reade[5] and Mr. A. Strahan[6] have shown that these are divisible into two groups: (1) an older set of tough blue boulder-clays and coarse gravels which only occur in the neighbourhood of the mountains; (2) a newer set of red and brown boulder-clays with intercalated beds of sand which are sometimes over 100 feet thick; these beds resemble the Holderness drifts, and have been called the "Low-level boulder-clays" by Mr. Reade.

The relations of the two deposits are well shown in the cliffs of Colwyn Bay, where the following succession is visible:—

		Feet.
Newer	4. Brown boulder-clay with broken shells and some northern erratics	8 to 12
	3. Obliquely stratified sands resting on an eroded surface	6 to 12
Older	2. Cream-coloured till in discontinuous patches	0 to 2
	1. Hard bluish gray till packed full of stones derived from the Carboniferous and Silurian rocks of Wales	seen for 6

Of the upper sands and clays Mr. Reade says, "they are not what the immediate coast or mountains could yield, but are composed principally of Triassic debris mixed with travelled and striated rocks." Near Llandulas, at a height of about 500 feet above the sea, there is an extensive deposit of stratified sand and gravel in which marine shells occur, and reddish boulder-clay rises to above 400 feet in the Vale of Clwyd.

In the west of Carnarvonshire there are vast accumulations of gravel and boulder beds which sweep up the slopes of the hills to heights of 800 and 1000 feet; and on the summit of Moel Tryfaen, a hill overlooking Carnarvon Bay, with a height of 1350 feet, there is an extensive deposit of stratified sand and gravel containing marine shells, more than sixty species having been obtained. Among the most abundant of these are *Tellina baltica*, *Cardium edule*, *Astarte borealis*, *Cyprina islandica*, and *Turritella communis*. It is irregularly overlain by boulder-clay, and both deposits contain erratics from Cumberland and Scotland, as well as chalk flints which came probably from Ireland. These flints, as Mr. Mackintosh observes, have travelled to a higher level than their source, for the highest parts of the Irish chalk are between 900 and 1000 feet.[7]

Similar shell-bearing gravels have been found by Mr. Mackintosh at heights of 1000 to 1230 feet on the east side of the hills near Minera in Denbighshire; here also Eskdale granite, Cumberland felstones, and Chalk flints are mixed with the debris of local rocks, and all are well rolled and rounded as if they had formed part of a sea-beach. This pebbly condition appears to be characteristic of the gravels between levels of 1000 and 1400 feet, while between heights of 500 and 1000 feet the stones in the drift are mostly angular. Above 1400 feet there are again angular gravels, and boulders of Arenig felstone occur in the Minera district up to a height of 1900 feet.

The low-level boulder-clays were formerly divided into an upper and lower clay with a middle sandy division, but Mr. Reade and Mr. Strahan, who are both well acquainted with the drifts of these counties, agree in thinking that the sands do not form anything like a continuous horizon, but are irregular beds developed at various horizons. Although there is no regular tripartite division of the

Fig. 180.—SECTION ALONG PART OF THE CLIFFS NEAR BLACKPOOL (by Mr. Mellard Reade). ■ Distance about three-quarters of a mile.

A.B. Red boulder-clay C.C. Stratified sand and gravel. D.E.H. Brown boulder-clay with many stones.

series, yet as a whole they exhibit much resemblance to the deposits of Holderness and East Lincolnshire, for the lower clays are generally purplish brown, and the uppermost clay resembles the Hessle Clay in being streaked and mottled with gray, and also in containing fewer stones.

A good section of the Lancashire drift is exposed in the cliffs near Blackpool (see Fig. 180). Here the lower bed of boulder-clay is harder and more stony than that forming the upper part of the cliff, but otherwise there is little difference between them; the intercalated sands and gravels are well stratified, and contain many marine shells. Occasionally, as at Lindal in North Lancashire, beds of peat with leaves and trunks of trees occur beneath a great thickness of boulder-clay.

Both the boulder-clays and the sands frequently contain marine shells and Foraminifera, those in the sands having doubtless been brought by the currents which carried the sand, but those in the boulder-clays are filled with fine silt charged with Foraminifera, showing that they have been picked up from silty shores and transported by ice. The shells have been found at various localities in Cheshire and Lancashire from sea-level up to 600 feet, and at 1200 feet near Macclesfield.

4. *Northern England*[a]

The Glaciation.—This is traceable chiefly to two main centres—the mountain cluster of the English Lake District, and the massive fells of Galloway in Scotland. Little record is left of the earlier phases of the Glacial period, but to the early sporadic radiation of boulders from these centres may be due much of the

[a] This section is a contribution from the pen of the late Mr. Hugh Miller, F.G.S., whose personal acquaintance with the district makes it more valuable than any description the author could have compiled from published sources.

strange intercrossing and intermingling that marks their after-distribution. In many cases they may have found their way into their present position, not from the parent rock direct, but from various points within the circles of early dispersal.

The striation of the Lake District must be attributed to glaciers which moved out through its radiating dales in almost every direction, the chief axis of movement being that of the principal watershed which runs through its centre approximately east and west. The lower valleys and their parting ridges, according to Mr. Clifton Ward,[8] became gradually buried under a confluent sheet of ice. In Galloway heavy glaciers moved out from the central granitic masses, and the glaciers of the two districts came together upon the plains of the Solway basin.

The further distribution of striæ and boulders is curious in the extreme. From Galloway it is remarkable that they pass very little to the northwards. On the west they bend along the coast as if to join the south-west stream of striæ making down from the Highlands through the now submerged valleys of Argyleshire upon the broader vale of St. Patrick's Channel. On the south they point freely southward, and their direction is continued over the Isle of Man and Anglesea. In the Lake District the same southward tendency is observable. Boulders of Cumbrian rocks do not range far to the north or north-west—not far beyond Carlisle—but stream off freely to the south. Moreover, from the eastern fells near Shap and those round the head of Lunedale they are shed southward over North Lancashire, not only down the valley of the Lune and along the low sea-board, but, as if regardless of gradients, over the Ingleborough district into Ribblesdale, crossing many considerable valleys, and overriding hills up to 1500 feet.

In easterly directions the evidence is still more curious. In the south-eastern part of Galloway, as was shown by Mr. J. Horne, the striæ point across the Solway, Criffell (1800 feet high) standing in the way somewhat like a graduated mark in a tide-way. The main stream of striation, joined towards the south by striæ and boulders from the Lake District, passes to the east coast of England. The greater part of it crosses the watershed between the Cheviots and the northern shoulder of Cross Fell (both of which hill-groups had small ice-caps of their own), at heights of from 600 to 1700 feet; it skirts the Cheviot range, the ice-borne boulders covering their flanks up to 1600 feet, but apparently at lessening heights as we trace them on. To the south of Cross Fell a smaller stream of boulders and striæ from Galloway and the Lake District concentrates upon the Stainmore Pass, and carries the boulders of Shap Fell to the east coast through Teesdale.[9]

Glacial Deposits.—It is not only in the striation of the rocks that these movements are recorded, but also in the structure of the till or lower boulder-clay, which enwraps the country with an irregular sheet of miscellaneous off-scourings, and extends from the flanks and hollows of the hills (as high sometimes as 1800 feet) down to the sea. The larger boulders embedded in the till are striated *in situ* in the same general direction, and with the same firmness and evenness as the striæ on the rocks; thus the till of Northumberland may be likened to one vast irregular "striated pavement." The smaller boulders and stones frequently have their longer axes drawn into the line of glaciation, as if by a heavy dragging force moving contemporaneously with the accumulation of the material. At the surface it is often shaped into sow-backs or *drumlins* stretched in the same direction. All these features of the till are remarkably developed on the watershed among the Bewcastle Wastes, north of Gilsland in Cumberland.[10]

The composition of the till, again, shows that the outcrops of rock lying in the path of movement—all the way from the red rocks of Cumberland, for instance, to the coaly shales of Newcastle—contributed one after the other their quota of materials, the boulders being gradually reduced in size and rubbed down into clay, etc., as if by sustained friction, as they were carried on. The texture and colour of the till thus constantly varies—it is bright Indian red on the red rocks; leaden-coloured and clayey on the carbonaceous rocks; sandy and raw where the pale carboniferous sandstones predominate; brown and dry on the Cheviot porphyry; and when it rests on composite formations such as the Carboniferous limestone series, it never remains for half an acre the same. Among the slopes of the higher hills it is thin, loose, local, angular, and almost morainic-looking; in the valleys and low grounds it becomes dense and well-kneaded up, and contains a larger assortment of boulders; in the lower grounds it is often gravelly and much intercalated with seams of sand and gravel and laminated clay without stones; but it is the same deposit throughout.

The overlying deposits are not so well understood. In the Isle of Man Mr. Horne describes an important section near Ramsey,[11] where a lower boulder-clay or till is overlain by finely-stratified sands and gravels, "evidently a marine deposit," above which is a stony clay (6 to 8 feet thick) resembling the maritime boulder-clay of Scotland. In West Cumberland Mr. J. D. Kendall [12] describes sands and stony clays which he believes to be a continuation of the uppermost sands and boulder-clays of Lancashire. On the coasts of Northumberland and Durham there is undoubtedly

an upper boulder-clay limited to the maritime districts, and to elevations under 350 feet, and lying in the track of the north and south coast glaciation. It is divided from the till either by stratified sand and gravel, or by an eroded junction line. It seems to be the same deposit, very uniform in character, that is found all along the sea-board from Aberdeenshire southward, differing from the till by its uniformly reddish colour and the fewness and smallness of its stones.

The latest deposits of the Glacial period in the north of England are, (1) the ridges and mounds of tumultuously stratified gravel and sand known as kames (or eskers), and (2) moraine mounds of angular debris. The moraines, which abound in the upper valleys of the Lake District, are the debris heaps of the last shrunken glaciers. In Northumberland they are few and small. The gravel mounds are of more equivocal origin. In some cases, near Otterburn in Northumberland, they merge into moraines; one part of a single mound may be moraine and the other part kame. These kames are of true morainic origin. The winding kame ridges, which, like the drumlins of the drift, extend in the direction of ice-movement (though only a single chain of them crosses the watershed of England, *i.e.* through the shallow watershed valley at Gilsland), are often supposed to be marine, but this is by no means certain, nor even probable.

5. *Central and Northern Scotland*

The following account of the Glacial phenomena of this region is taken principally from Sir A. Geikie's *Memoir on the Phenomena of the Glacial Drift of Scotland*,[13] supplemented by some additions from more recent sources.

Glaciation.—The rocky regions of Scotland nearly everywhere exhibit the peculiar rounded and moulded outline which is characteristic of ice-action, and nowhere are these swelling contours more distinct than on the slopes which rise from the central lowlands. Wherever, too, the smoothed surfaces of the rocks have been protected from atmospheric influences by a covering of turf or clay they exhibit the striations and groovings left by the passage of ice-borne stones; such striated surfaces occur not only on the summits and flanks of lofty mountains, but also along the shores of the lochs and firths, and are often seen to pass beneath the level of the sea.

Observation has shown that, as a general rule, the striæ run parallel to the main valleys of the country, and that they radiate outwards from the great central mountain ranges. Thus there

is ample proof that the Grampians formed one axis of dispersal, for down the valleys which open on to the Clyde the striæ run south or south-east, down Loch Fyne they run south-west, while at the north end of Loch Awe, and thence over the country to Loch Linnhe, the direction is uniformly from east to west; down the valley of the Spey they run north-east, in Aberdeen nearly due east, while in Perth, Fife, and Forfar the directions are south-east and east-south-east. The highlands of Sutherland formed another centre whence the ice radiated in every direction.

There are, however, exceptions to the coincidence between the direction of the striæ and that of the main valleys; thus the district known as Knapdale in Argyleshire, which rises to 700 or 800 feet above the sea, is glaciated obliquely from north-east to south-west, as if the ice had filled up the valley of Loch Fyne, and had flowed over the ridge to the Sound of Jura. There seems also to have been a time when the ice from the Perthshire highlands went across the Ochil Hills, some of which reach a height of 2300 feet, and these are important facts to remember when the mode of glaciation is considered.

Glacial Deposits.—The following is a general classification of these deposits, but it is seldom that all the members are found in one locality, and it is probable that the moraines were more or less contemporaneous with the later shell-bearing clays:—

5. Kames and raised beaches.
4. Moraines of local glaciers.
3. Shell-bearing clays near the coast.
2. Upper boulder-clays with stratified sands and gravels.
1. Lower boulder-clay or till.

The till is described as a very stiff clay full of stones and boulders, or rather as a mixture of gritty clay, gravel, and boulders, the whole being so hard and compact that it often weathers like a conglomerate. Boulder-clay of this kind occurs up to heights of 1600 feet, and is sometimes over 100 feet thick, being always thickest on the low grounds and thinning away on the highland slopes. The stones and boulders found at any given locality are principally derived from local rocks, and in the low-land clays there are not many stones which have travelled more than a few miles from their parent site; most of the fragments are smoothed and striated, and many are scratched all over, often exhibiting five or six definitely striated surfaces. The local character of the clay is also shown by its variations in colour. Hugh Miller, sen., long ago remarked that red sandstones were covered by red boulder-clay, the gray flags of Caithness by a lead-coloured clay, and the coal-measures of the Lothians by a

bluish black clay; subsequent observations have shown that the clays of these colours do not exactly coincide with the limits of the formations from which they derive their tint, but slightly overlap them in an outward direction; thus in the basin of the Forth the red clay passes eastward on to the coal-measures for a certain distance before it is replaced by the clay which derives its tint from those measures.

Thus, though the materials of this inland boulder-clay afford evidence of a certain amount of transport, still its local character is so strongly marked, that "whatever may have been its mode of production, it cannot have been carried from a distance, but must have been formed on the whole in the districts in which it is found."

In many places the hard till or boulder-clay above described is covered by deposits of a more varied character, consisting of stratified sand, gravel, and clay; such deposits occupy large areas in the central lowlands between the firths of Forth and Clyde. Associated with these beds or stranded on bare hill-sides are numerous large erratics or isolated boulders, which have usually come from points to the north or north-west of the positions they now occupy, and some have travelled distances of 50 or 60 miles; it is to be noted that such boulders rarely or never occur in the older boulder-clay, though they often lie on it.

A good example of the stratified beds is found in the Isle of Arran; the beds are exposed in the banks of the burns near Lag from 80 to 100 feet above the sea, and are as follows:—

	Feet.
Beds of gravel, sand, and clay	15
Reddish clay with shells of Arctic species	7 to 10
Hard brown boulder-clay or till	seen for 20

Along the coast of Aberdeen, from Stonehaven to Peterhead, a very different kind of boulder-clay is found; this is a reddish brown clay which appears to resemble the brown clays of Yorkshire and Lincolnshire. It contains broken marine shells, and often includes seams of fine sand or laminated silt; moreover, its materials appear to have been derived from the southward, from the Old Red Sandstone districts in Kincardine and Forfar, a conclusion which is confirmed by the occurrence of striæ on the rocks below, pointing from S.S.W. to N.N.E. Near Collieston and Slains this clay rests on a set of stratified sands and gravels which are more than 50 feet thick, and contain numerous broken marine shells, but these seem to have been derived from the destruction of Pliocene beds, comparable to the English crags. The red clay varies from 10 to 30 feet in thickness, and reaches inland up to heights of 300 feet, while pebbly gravels with broken shells range up to 470 feet.

In the basin of the Clyde there are certain deposits which were evidently formed during the last stage of the Glacial epoch. The usual succession of these beds is as follows :—

Clyde beds	3.	Sandy clay or sandy gravel.
	2.	Fine gray clay with many perfect shells.
	1.	Laminated reddish clay without shells.
Till.		Hard tough boulder-clay with striated stones.

There is always a layer of laminated, stoneless, and shell-less clay between the till and the shell-bearing clay (No. 2), but its thickness varies from 1 to 18 feet. The clay above is a consolidated mud through which many stones, both rounded and angular, are scattered, but its consistency is not that of boulder-clay, and the stones are not glaciated ; the shells which occur in it are generally perfect, and are of northern and Arctic species. These clays fringe the Firth of Clyde from Glasgow westward, and pass up the Kyles of Bute to Loch Fyne ; they are also found on the shore of Loch Lomond, but do not anywhere extend beyond 50 feet above the sea.

Inland the last phase of the Glacial epoch is marked by the occurrence of terminal moraines in many of the Highland valleys ; sometimes several such moraines occur one above another, and huge blocks of rock are often perched on the top of them as well as on the neighbouring slopes, while the course of the glen above the highest moraine is swept clear of all such detritus.

Kames are found in some districts, and Mr. Hugh Miller observed that in Easter Ross the ends of all the kames are markedly levelled out into horizontally stratified sheets of gravel all along the line of the 100-foot beach of that district.

6. *Ireland*

Glaciation.—The glaciation of Ireland presents some remarkable features ; the prevalence of ice-marks running from N.N.W. to S.S.E., and the frequent occurrence of roches moutonnées sloping to the N.N.W., prove that there was a time when the general movement of the ice was from that direction. This general trend is particularly noticeable throughout the southern, central, and eastern parts of the country ; in Connaught and Ulster, however, the ice-marks vary greatly in direction, pointing south-west about Galway Bay, W.N.W. round Clew Bay, due north round Killala Bay, north-west down the valley of Lough Erne, and north-east in Tyrone. It is probable that the striæ have not all been produced at the same time or by the same agent ; that some were made by the early glaciers, some by an ice-sheet or ice-stream during a time of submergence, and some by the later glaciers which occupied the

mountains on their re-elevation, and it is obviously difficult to distinguish between the striæ made at these different stages of the Glacial episode. Mr. J. R. Kilroe has shown that in the north-west of Ireland two sets of striæ can be distinguished, the one being due to a local glaciation and the other to a flow of ice from the west of Scotland.[14]

Glacial Deposits.—Ireland is largely covered by Glacial deposits, about which much has been written, but no satisfactory or comprehensive account of them has yet been published. Enough is known, however, to make it obvious that they were accumulated under the same conditions as those of England ; those of Northern and Eastern Ireland, indeed, greatly resemble the drifts of Western England, but those of the central and western districts constitute rather a different type.

The central plain of Ireland "is largely covered by a widely spread mass of drift, consisting of dark sandy clay with pebbles and blocks, and occasional beds of sand and gravel, which are sometimes very regularly stratified. The great majority of the pebbles are rounded fragments of Carboniferous limestone, whence the deposit usually goes by the name of the Limestone Drift. This deposit rests not only on the limestone, but sweeps up on to the flanks of all the hills which rise from the central plain. In such case the Limestone gravel (often) becomes largely mingled with the detritus of the rocks of which the hills are made, . . . but gravel almost entirely composed of limestone pebbles is found up to heights of 1200 feet on the granite mountains south of Dublin. It spreads across the lower part of this granite range, and runs down by Bray into the county Wicklow, where it is covered by beds of sand and marl that spread through Wicklow and Wexford over all the low grounds between the mountains and the sea-coast."

In some cases this Limestone Drift overlies a deposit composed entirely of local rocks, as in Glenbarrow, on the northern flank of the Slieve Bloom. Here at a height of 800 feet the river runs below a cliff 120 feet high, which is entirely formed of stratified drift, and exhibits the following succession :—

	Feet.
Coarse drift with limestone boulders	50
Fine laminated sand	20
Rubbly sand, with angular blocks of Old Red Sandstone, the same rock lying below	50

On the north-east coast there are deposits similar in all respects to the low-level drifts of Lancashire, consisting of red and brown boulder-clays, with frequent intercalations of sand containing marine shells. Cliff-sections of such beds are frequent along the

coasts of Antrim and Down, and their marine origin is proved not only by the shells in the sands, but by the presence of *Nuculana pernula* and *Nuculana minuta* with attached valves in boulder-clay at Woodburn Glen, near Belfast.[15]

Southwards these reddish clays appear to overlie the limestone drift, as seen in the cliff-sections at Killiney and Ballybrack, south of Dublin, and they attain a great thickness near Carlow, where the following succession was found in sinking a colliery shaft :—

		Feet.
Newer Drift	Stiff red clay with stones . .	84
	Laminated clay	5
Limestone Drift	Sand with pebbles of limestone .	25
	Strong clay with stones . .	8
		122

Drifts with marine shells occur again in Wicklow and Wexford, chiefly below 600 feet, but on Three Rock Mountain in Wexford they occur at a height of 1300 feet, and include some more southern forms, as *Dosinia lincta*, *Venus striatula*, and *Venus casina*.

No notice of Irish drifts would be complete without a reference to the long winding banks or ridges of gravel which are known as eskers. These ridges often rest on the surface of the other Glacial deposits, and from these the materials composing them have been chiefly derived. They often extend in sinuous lines for many miles, but are confined to the plains and low grounds, not extending above the 400 feet contour. They may therefore be regarded as among the latest of the Pleistocene deposits, but the occurrence of large boulders on these banks shows that floating ice was still present.

Morainic mounds occur in some of the valleys of the more mountainous regions, and testify to the existence of small valley glaciers during the last stage of the Glacial period.

B. Non-Glacial Deposits

As mentioned on p. 540, the older river gravels and the older cavern deposits appear to be of about the same age, and in both the stone weapons of Palæolithic man are associated with the bones of many extinct animals. In some places it seems possible to distinguish two Palæolithic horizons or ages, an older of roughly made implements associated with *Elephas antiquus*, and a newer of more finished weapons, for which the name *Mesolithic* has been proposed. Some authorities recognise a third age, that in which remains of the reindeer are abundant, associated with a special type of flint

implements. If the latter is in real succession and not a mere local variation the Pleistocene (non-Glacial) succession may be tabulated as follows :—

4. Neolithic, the age of domesticated animals.
3. } Mesolithic { the age of the reindeer (*Rangifer tarandus*).
2. } { the age of *Elephas primigenius* and *Rhinoceros tichorhinus*.
1. Palæolithic, the age of *Elephas antiquus*.

It would be impossible within the limits of this volume to give anything like a comprehensive account of the river gravels, cave earths, raised beaches, and other non-Glacial deposits in Britain. Only a few examples will therefore be described in the following pages.

Cave Deposits.—The origin of caves and the formation of the deposits found in them is explained in most books on Physical Geology. Many such caves have now been explored in England and Wales; some of them have served as dens for bears or for hyænas, and the bones of other animals belong to carcases which have been dragged in by these creatures. At other times they have served as shelters for man, whose occupation of them is proved by the frequent occurrence of stone implements—Palæolithic in the lower beds, and sometimes Neolithic in the higher. The caves of Creswell Crags in the Magnesian Limestone on the borders of Derby and Notts afford good examples of such deposits.[16] In Robin Hood Cave the beds found were :—

	Feet.
5. Stalagmite united to the roof	1 to 2
4. Breccia with bones and implements	0 to 3
3. Cave earth with bones and implements	2 to 4
2. Red clayey sand with bones	2 to 4
1. Light-coloured sand with blocks of limestone fallen from the roof	2

The lowest sand yielded no organic remains, but the red sand contained bones of many animals, all of them scored with the teeth-marks of the creatures which had dragged them into the cave, and that these were hyænas is proved by the abundance of hyæna bones and teeth belonging to individuals of all ages from cubhood upwards. Flint implements are rare in the sand, but abound in the overlying cave earth, some consisting of flint and others of quartzite, but all of Palæolithic form; bones of the same animals occur in this layer. Lastly, in the breccia above are flint and bone implements of the more highly finished type which is known as Neolithic, and fashioned, according to Professor Dawkins, by a different race of men to the earlier inhabitants.

Some caves in the Vale of Clwyd (North Wales) have been explored by the late Dr. Hicks, and are important from their position in relation to the local Glacial deposits.[17] They are known as the Ffynnon Benno and Cae Gwyn caves, and are situate in a small valley or ravine on the east side of the Vale at a level of nearly 400 feet above the sea. The valley has apparently been filled with Glacial drift of the low-level Lancashire type (see p. 552), and one of the entrances to the Cae Gwyn cave was found to be buried beneath a bank of stratified sand, gravel, and boulder-clay, the lower layers of which entered the cave and overlay the bone-bearing cave earth. The section at this entrance was as follows :—

	Feet.	Inches.
Reddish boulder-clay with sandy seams . . .	6	4
Sand with boulders and seams of clay . . .	3	9
Gravelly sand with fine laminated sand below . .	3	5
Red laminated clay	1	0
Cave earth with bones and flint implements . .	from 2 to 5	

Moreover, in the other cave the bone earth had been disturbed, the stalagmite floor in places broken up, and large stalactites had been broken off, the whole being covered by clays and sands containing pebbles from distant sources. Dr. Hicks concluded that the contents of the cave are pre-glacial, but this was not proved by the evidence, and the assemblage of mammalia is that of the later Palæolithic time, the commonest species being *Rhinoceros tichorhinus*, *Elephas primigenius* (the mammoth), and *Rangifer tarandus* (reindeer). They must, therefore, be regarded as inter-glacial, but anterior to the submergence which enabled the northern ice to travel so far southward.

Another important cavern is that known as Kent's Cavern, near Torquay in Devon. This was explored by Mr. Pengelly with assistance from the British Association, and classified collections of its contents may be seen in the museums at Torquay, South Kensington, and Oxford. Where the succession was complete it read as follows :—

5. Black mould.
4. Granular stalagmite (5 feet) with some bones.
3. Cave earth with many bones and Palæolithic implements.
2. Hard crystalline stalagmite (6 to 10 feet) with bones of bears.
1. Breccia with bones of bears and rude stone implements.

The cave seems to have been first occupied by bears and occasionally by men of early Palæolithic race. In the cave earth (No. 3) hyæna bones are the most abundant, but remains of twenty-

five other mammals were found, including *Elephas primigenius*, *Rhinoceros tichorhinus*, and *Rangifer tarandus*. With these were associated flint implements of two recognised Palæolithic types and a few tools made of bone. This deposit evidently represents a long period of time, and is covered by the upper stalagmite containing remains of hyæna, mammoth, fox, and horse.

Another well-known cave is that at Brixham on the south side of Torbay. Fig. 181 is a diagrammatic view of this cave and of the deposits found in it. The gravel at the bottom contained a few rude Palæolithic implements and a few bones of bears and of the mammoth. The cave earth contained an assemblage similar to that of Kent's Cavern.

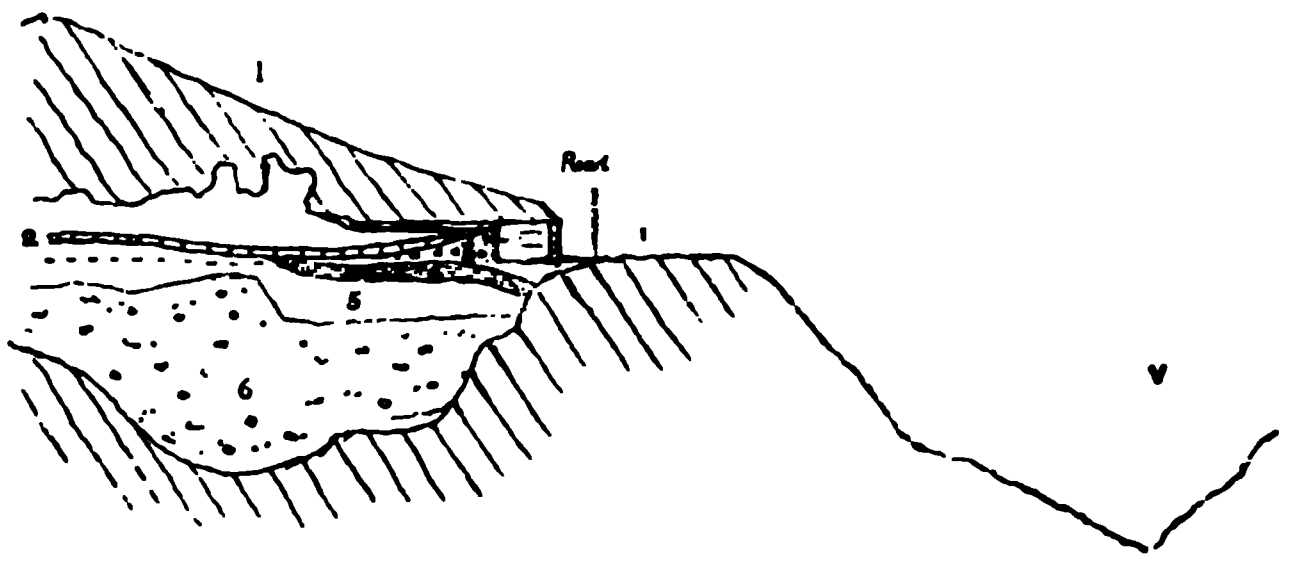

Fig. 181.—SECTION THROUGH THE BONE CAVE AT BRIXHAM, DEVON.

2.	Stalagmite floor and three calcareous breccia . .	1 to 2 feet
4.	Black loal near entrance only	2 ,,
5.	Reddish cave earth with many bones	2 to 4 ,,
6.	Water-worn gravel or shingle	2 to 12 ,,

River Gravels.—The manner in which disconnected tracts and terraces of gravel, sand, and loam have been formed and left at various levels in a river-valley is explained in all text-books of Physical Geology. They represent different stages in the excavation of a valley, those at the highest level above the existing stream being of course the oldest, and the others newer in proportion as they are nearer to the level of the modern alluvium.

The deposits in the valley of the Thames may be taken as an example of such accumulations. In the higher parts of the valley tracts of gravel are found at various heights, now on one side of the river, now on the other; three stages or terraces can often be distinguished, the highest being about 30 feet above the level of the river. From this highest terrace few bones have been obtained, but at the lower levels land and river shells, with remains of *Elephas*

primigenius, *Elephas antiquus*, *Rhinoceros tichorhinus*, *Bison priscus*, *Rangifer tarandus*, *Equus caballus*, *Canis lupus*, and *Ursus arctos* are frequently found. Between Windsor and London the outspreads of gravel become wider and more continuous, but the surface of the older parts still rises to 30, and even 45 feet above the river, and the shells are still of fluviatile species. Hence we may conclude that when these gravels were deposited the Thames had a much longer course than it has at present, and that this part of the valley

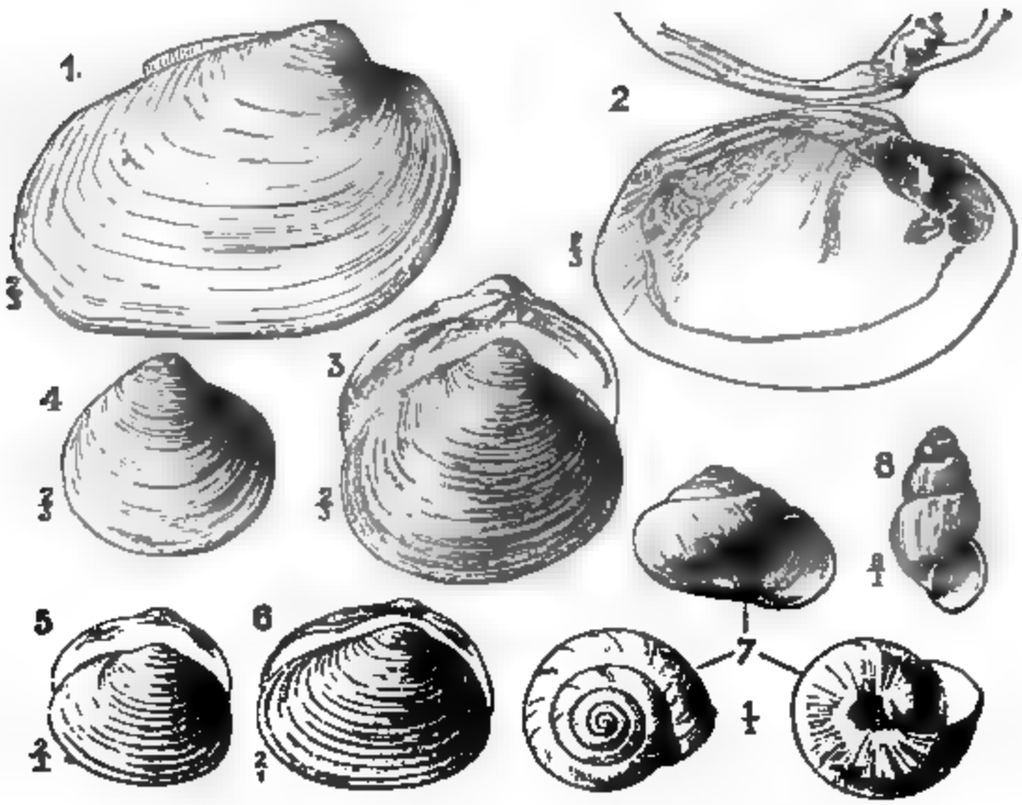

Fig. 182.—LAND AND FRESHWATER SHELLS WHICH ARE EXTINCT IN BRITAIN.

1. Unio littoralis.
2. Interior of U. littoralis.
3 and 4. Corbicula fluminalis.
5. Pisidium astartoides.
6. Pisidium amnicum.
7. Helix (Eulota) fruticum.
8. Hydrobia marginata.

was then far inland, otherwise the beds would be at a lower level and the shells would be estuarine. In these gravels, at Acton and Stoke Newington, many flint implements of Palæolithic type have been found.

Below London, at Ilford, Grays, Crayford, and Erith, there are a series of gravels, sands, and loams which rise to 25 or 30 feet above the river, but are nearly 60 feet above the base of the alluvium at Erith. These beds have yielded the mammalian remains mentioned above, and it is only at these places that *Rhinoceros*

leptorhinus and *R. tichorhinus* have been found together. The presence of *Rhinoceros megarhinus* (a Pliocene form) and the absence of the reindeer (*Rangifer tarandus*) are regarded as indications of the antiquity of the deposits. Between fifty and sixty species of land and freshwater shells have been found, several of which no longer live in Britain, *e.g. Cyrena* (*Corbicula*) *fluminalis*, *Unio littoralis*, *Pisidium amnicum*, *Hydrobia marginata*, and *Helix fruticum*. A worked flake proving the presence of Man has also been found in the lower brick earth.

The district now drained by the river Cam contains an interesting series of river deposits which bear testimony to the successive changes that have taken place in the drainage system of this area. The oldest line of gravels has no connection with the modern river-valley, but crosses it nearly at right angles near Cambridge. Patches of gravel in the hill-valleys near Balsham testify to the action of streams where none now exist, and these seem to have united to form a river which ran by Wilbraham, Quy, Cambridge, Girton, Oakington, Long Stanton, and Willingham.[18]

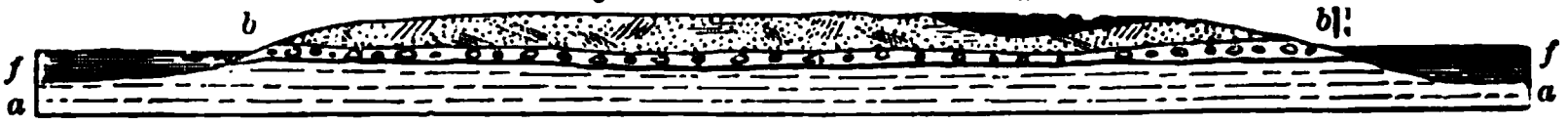

Fig. 188.—DIAGRAMMATIC SECTION ACROSS THE OLD GRAVEL RIDGE AT MARCH.

f. Fen deposits. *d*. Loam. *c*. Gravel and sand. *b*. Boulder-Clay. *a*. Kimeridge Clay.

The deposits it has left now form long gravel-capped ridges, the base of the gravels where intersected by the Cam being about 40, and their surface sometimes 60 feet above the modern alluvium. These fluviatile gravels appear to terminate abruptly near the fens of the Bedford Level, but were probably originally continuous with the gravels at Chatteris, Doddington, and March, which form similar ridges rising above the general level of the fens which surround them, and evidently mark the estuarine channel of a river which traversed the country when it stood at a somewhat lower level, and before the Fen-land existed. The shells found at March are chiefly marine, but include *Corbicula fluminalis*.

Of deposits which bear a definite relation to the modern river Cam, remains of three terraces can be recognised. The highest of them runs by Trumpington and Barnwell, about 25 feet above the alluvium, and has yielded a number of mammalian bones and teeth, with a still larger number of shells, among which *Corbicula fluminalis*, *Unio littoralis*, and *Hydrobia marginata* occur. These three shells do not occur in the lower terraces, which are respectively about 15 and 8 feet above the alluvium near Cambridge.

Raised Beaches.—Elevation of the land is also attested by the raised beaches and sea-margins which occur along many parts of the British coast-line. The beaches consist of sand and gravel, irregularly stratified, and often containing drifted shells, such as may be found on modern shores. Deposits of this kind occur at Brighton and westward along the southern part of Sussex as far as Portsdown Hill, the highest level at which they are found being about 100 feet above the sea. Inland they are banked against an old line of cliffs, the position of which is shown in Fig. 147. Raised beaches exist also at Portland Bill, where the highest part of the deposit is 50 feet above sea-level, and at many places round the coasts of Devon and Cornwall.[19] On the Scottish coasts raised beaches and lines of cliff are found at various successive levels between 25 and 100 feet above high-water mark, four or five sometimes occurring one above another.

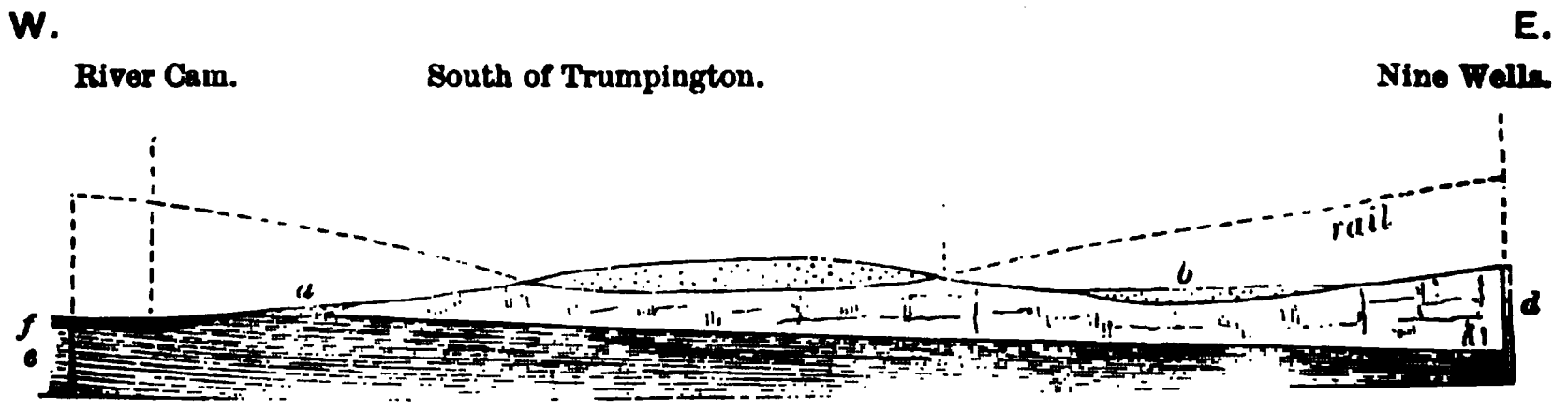

Fig. 184.—SECTION ACROSS THE TRUMPINGTON GRAVELS. Distance 2 miles.

a. Lowest terrace.
b. Second terrace.
c. Highest terrace.
d. Chalk marl.
e. Gault.
f. Alluvium.

Alluvial Levels.—These are marshy flats formed of the deposits left by the flood-waters of a river; they border the actual channel of the river and widen out in the lower part of its valley, till near the river's mouth they often form wide levels or marshes, which are partly of fluviatile and partly of marine origin. The depth of alluvial matter which occupies the ancient valleys of our rivers near their mouths is sometimes very great; thus at Sheerness, and also at Upchurch, near Sheppey Island, borings have proved 77 feet of such alluvium. In the Essex marshes there is sometimes 50 feet of alluvial matter. At Yarmouth there is said to be 170 feet, and in the valleys of the Yare and Wensum there appears to be sometimes 60 or 70 feet of alluvium between the present surface and the chalk which lies at the bottom of the valley.

In the Vale of Pickering, in Yorkshire, a deep deposit of alluvial matter has accumulated behind the bank of boulder-clay which blocks the seaward end of the valley, forming the great

"flats" and "ings" near the villages of Wilton, Allerston, Ebberston, and Swainton. The deposits consist of soft clays and sands, which are sometimes 60, 70, and even 100 feet deep, resting usually on a layer of gravel from which a water-supply is obtained.

Besides the deposits above mentioned which lie within river-valleys, there are other tracts round our shores which have once been bays and inlets of the sea, and are now filled principally with marine silts and clays, though layers of peat with trunks of trees are frequently intercalated with the silts, and mark pauses in the process of silting up. Many such tracts pass beneath the present beaches, and were evidently once much more extensive than they are now. Such are the marshes near Fleetwood, in Lancashire, the Bridgewater Levels in Somerset which pass beneath the Bristol Channel, and must formerly have extended far down this estuary, the Pevensey Levels in Sussex, the Romney marshes in Kent, the Fens of Cambridge and Lincoln, and the marshes of the East Lincolnshire coast.

GEOGRAPHICAL AND CLIMATAL CONDITIONS OF THE PLEISTOCENE PERIOD

The Arctic plants in the thin layer underlying the lowest boulder-clay of Cromer indicate a great and sudden increase of cold, and the overlying boulder-clays are the acknowledged product of ice-action, though opinions differ as to whether the principal agent engaged in their formation was sea-ice or land-ice.

So far as we know there are only three sets of causes which could have wrought such a change of climate; these are (1) cosmical and astronomical causes affecting the whole globe; (2) local and geographical causes involving the connection or disconnection of continents, and the consequent divergence or introduction of marine currents; (3) alterations in the arrangement of the areas of high and low barometric pressure, affecting the direction of prevalent winds.

(1) The earth's orbit or path round the sun is not a circle, but an ellipse, the form of which is subject to a certain amount of variation; the sun occupies one of the foci of this ellipse, and when the earth is at the end nearer to this focus it is said to be in *perihelion*, when at the other end it is in *aphelion*. When the eccentricity of the orbit is great, and the winter of one hemisphere occurs during the period of aphelion, the amount of heat received from the sun must be greatly reduced, and the winter temperature must consequently be greatly lowered; moreover, the length of

winter would be increased, so that at such a time it would be no less than thirty-six days longer than the summer (its length at the present time being eight days shorter than that of the summer).

The result of such conditions, viz. a lowering of the temperature and a lengthening of the winter in, say, the northern hemisphere, would be that much of what previously fell as rain would then fall as snow, and a greater fall of snow means a greater accumulation of ice in the northern regions. But since the summers would occur in perihelion, and the heat received from the sun would thus be greater than it is now, it might be thought that this heat would be sufficient to dispel the ice and snow accumulated during the long cold winters. Mr. Croll, however, has shown that, in spite of the greater amount of heat then received, the actual temperature of the air near the earth's surface would be lower than it is now. There are, he says, three ways by which accumulated masses of ice and snow tend to lower the summer temperature, viz. :—

(*a*) The temperature of the snow and ice can never rise above the freezing-point, however hot the sun's rays may be, and consequently the air is cooled by contact with the snow more rapidly than it is heated by the sun, for air is not a good absorbent of radiant heat; hence in a country like Greenland the temperature of the air even during summer never rises much above the freezing-point.

(*b*) The rays falling on a surface of snow and ice are disposed of in two ways: some are reflected back into space; others are absorbed, but do not raise the temperature, for they are used up in melting a portion of the ice.

(*c*) The great strength of the sun's rays at the beginning of summer would produce an increased amount of evaporation; but the presence of snow-clad mountains would chill the atmosphere, and condense the vapour into thick fogs such as often envelop the Antarctic regions during summer at the present time. These fogs, by cutting off the sun's rays, prevent the further melting of the snow and ice, and make the summer temperature of these regions actually lower than that of the northern regions, in spite of the summer occurring in perihelion.

(2) Let us next examine the probable geographical conditions of the period. The probable land connection between Scotland and Greenland during Tertiary time has already been mentioned, and there is every reason to suppose that it continued to exist till the beginning of Pleistocene time; all authorities are agreed that the western part of the British Islands then stood at a much higher level than they do now, that England was joined to the Continent, and that Ireland was probably united to England, and consequently

that all our mountainous regions rose to much greater elevations. It is hardly necessary to point out that a greater extent of land with more lofty mountains are conditions which would favour a greater accumulation of snow.

Assuming, then, the persistence of the barrier between the Arctic and Atlantic Oceans, what changes can be indicated as likely to bring a cold current into the Atlantic from the north-west?—for the existence of such a current seems to be proved by the prevalent direction of ice-marks in Ireland and the north-west of England, and by the facts connected with the dispersal of erratics. It has been suggested that the submergence of the Baffin's Bay area may have taken place at this time, and that by this means a cold Arctic current was introduced into the Atlantic, and would in all probability flow eastward along the western side of that land of which our islands formed a part. By such an arrangement any warm current such as the modern "gulf stream" would be cut off from our north-west coasts, and compelled to take a more southerly course.

Dr. Croll, however, has adduced very good reasons for supposing that no such powerful current as the Gulf Stream then entered the North Atlantic. He points out that the strength of the trade winds depends on the difference of temperature that may exist between the equatorial and polar regions, the winds being strongest in that hemisphere where the greatest difference exists. When this occurred in the northern hemisphere the influence of the northern trades would extend considerably south of the equator, and this would affect the great ocean currents, tending to impel them southwards.

(3) The alteration of meteorological conditions as a cause of climatal change has recently been discussed by Mr. F. W. Harmer,[20] who points out that the winds are an important factor in determining the distribution of climatal zones, and that existing deviations of the monthly or yearly isotherms from the normal are coincident generally with the direction of the prevalent winds. "The winds blow in a direction more or less parallel to the isobars; the latter group themselves round centres of high and low pressure. . . . Anomalous weather is due to some unusual arrangement of these areas; similarly former cases of anomalous climate can only have occurred when meteorological conditions were favourable.

"During the Glacial period the regions covered by ice might have been, to a greater or less extent, anticyclonic at all seasons, low-pressure systems prevailing at the same time over the warmer regions immediately to the south of them and over the adjoining oceans. The relative positions of areas of high and low barometric pressure, the direction of the prevalent winds, and the consequent

distribution of climatic zones would in such a case have differed from those of the present time."

The prevalence of south-westerly winds over the British area at the present time is due to the fact that the centres of cyclonic storms generally pass from the Atlantic to the north or north-west of our islands. Under the conditions above imagined they would pass farther to the south, bringing oceanic winds over the Sahara and the Mediterranean Sea, while easterly winds would prevail over Britain. It has already been mentioned that the shell-banks of the Suffolk and Norfolk crags afford actual evidence of such easterly winds during the later part of the Pliocene period. Further, as Mr. Harmer points out, "the diversion of the prevalent winds of the northern part of the north Atlantic from a south-westerly to a south-easterly direction would have tended to divert the Gulf Stream, or what remained of it, towards the American coast." This abstraction of the Gulf Stream would have an enormous effect on the climate of Western Europe, equivalent, according to Dr. Croll, to a lowering of the mean annual temperature of London by 40° F.

There can be little doubt, therefore, that if any two of the above-mentioned causes happened to be coincident, a period of very severe cold would be produced in the northern hemisphere, or at any rate in the Europ-Asiatic portion of it; and it is quite possible that the glaciation of Europe and of North America was not contemporaneous, but alternating, *i.e.* the time of maximum glaciation in the one region corresponding with a minimum of glaciation in the other.

In the descriptive section it has been mentioned that glaciated surfaces are common throughout the northern parts of Britain, and that similar markings occur beneath the boulder-clays which cover the lowlands; much of this glaciation was doubtless effected by land-ice at the commencement of the Glacial period, when the land stood at a high level. The country seems then to have been covered by a vast system of glaciers, which may have been confluent on the lower ground, and have formed an ice-sheet like that which envelops Greenland at the present day. The Highlands of Scotland evidently formed the largest centre of dispersal, but independent snowfields existed over the southern uplands, the English Lake District, Wales, and Northern Ireland. The principal result of these slowly-moving ice-caps may be described as a general scraping and scouring of the land beneath them; all its rocky prominences were smoothed and rounded off, the pre-Glacial soils and river gravels and the outer weathered portions of all rock surfaces were ground up and pushed along down the valleys and out on to the plains below.

The hard *till* or lower boulder-clay is believed to have been formed under this ice-sheet, and some authorities consider it to have been accumulated as a "moraine profonde" beneath the ice which rested on the land; but others question the possibility of such a universal layer of detritus existing beneath an ice-sheet, and suggest that this boulder-clay was laid down below the level of the sea, where the ice displaced the sea-water, but began to rise or lift itself from the ground over which it passed.

With regard to the later boulder-clays and those which spread over so large a part of England, it is probable that sea-ice was chiefly concerned in their formation. Most writers admit that after the ice had reached its maximum thickness and extension, a general movement of submergence set in, which must have brought the sea-ice farther and farther over the land. During this phase of the period the outer parts of the ice-sheet would be broken up by the sea-waves, the huge icebergs thus formed being mingled with the floes brought from more northern regions by the two Arctic currents, and both yielding their burdens of mud and stones to swell the deposits of boulder-clay that were being formed round the sinking shores. Every winter saw our islands fast bound in immovable ice, but every spring and summer, when the coast-ice broke up and was driven southward by winds and currents, found the water-level a little higher, and saw the deposits of clay and gravel carried a little farther up the submerged slopes. It appears certain, however, that the southern part of England was never covered by ice, nor submerged to a greater extent than 100 feet.

From the icy sea in which it was partially submerged Britain gradually rose again, and as the mountains rose higher and higher above the water they were again covered by ice and snow, but these did not accumulate to anything like their previous thickness, because the conditions which had caused the Glacial episode in the northern hemisphere were now passing away. Snowfields, however, formed on the hills of Scotland, Ireland, Cumberland, and Wales, generating local glaciers which have left small moraines to mark the limits of their descent down the valleys.

The rainfall, however, was probably greater than it is now, and the country being covered with an almost universal mantle of boulder-clay, no large tracts of pervious rock were then exposed, such as now absorb a portion of the rainfall; consequently, nearly all the rain was shed off the land in the shape of running water, all the streams and rivers were larger and swifter than they are at present, and the process of valley erosion was thus carried on at a rapid rate.

Since the Glacial deposits to a great extent draped the pre-Glacial surface of the country without completely filling up the pre-existent valleys, the streams were naturally directed into the same depressions; but the channel which each began to carve out of the Glacial beds did not everywhere coincide with that of the river which occupied the valley in pre-Glacial times, so that in many cases we have a post-Glacial valley system superposed upon an antecedent one, as in the case of the Mersey and of many rivers in Scotland. Cases also occur where the older valleys have been blocked up by Glacial deposits at certain points so that the post-Glacial streams were ponded back, and have made new channels for themselves through the country between the older valleys; interesting instances of this occur in Lincolnshire.[21]

The phenomena of the buried forests, which in some places descend to as much as 70 feet below the present sea-level, show that the land continued to rise until it stood at least that much higher out of the sea than it does now, and that the last movement throughout the greater part of England has been one of subsidence. In Scotland, on the contrary, there has been no such recent subsidence; the old forest levels seldom run below low-water mark, and they are covered by marine clays which are now raised to a height of from 30 to 45 feet above mean sea-level. This means that the latest movement in Scotland was one of elevation.

In England the subsidence put an end to the process of valley excavation, the rivers ceased to deepen their channels, and commenced to form the alluvial levels which are so characteristic of English lowland valleys; thus it happens that the seaward ends of many valleys are silted up to great depths below the present alluvial levels, while even in the higher parts of these valleys the base of the more recent river gravels lies below the bed of the modern stream.

We have now brought the history of Britain down to a recent date, geologically speaking, though we leave it still in what is usually called prehistoric time. To study and describe the relics of the early human inhabitants of our islands belongs rather to the province of the antiquary than to that of the geologist, though the subject may also be treated from a geological point of view, as in Professor Boyd Dawkins's *Early Man in Britain*, to which the reader is referred.

References

[1] For the Glacial deposits of Cromer see C. Reid in *Geol. Mag.* Dec. 2, vol. vii. p. 548, and the "Geology of Cromer," *Mem. Geol. Survey.*

[2] On the Drifts of Lincolnshire see the *Memoirs of the Geological Survey* and *Quart. Journ. Geol. Soc.* vol. xli. p. 118.

[3] On the drifts of Holderness consult the "Geology of Holderness," by C. Reid, *Mem. Geol. Survey*, and the drifts of Flamborough Head, by G. W. Lamplugh, *Quart. Journ. Geol. Soc.* vol. xlvii. p. 384.

[4] See *Physical Geology and Geography of Great Britain*, by A. C. Ramsay (sixth edition).

[5] On the "Drift-Beds of the North-West of England," *Quart. Journ. Geol. Soc.* vol. xxxix. p. 83.

[6] "Geology of the Country round Chester," by A. Strahan, *Mem. Geol. Survey* and *Quart. Journ. Geol. Soc.* vol. xlii. p. 486.

[7] D. Mackintosh in *Quart. Journ. Geol. Soc.* vol. xxxvii. p. 366.

[8] Clifton Ward on the "Glaciation of the Lake District," *Quart. Journ. Geol. Soc.* vol. xxix. p. 422 (1873), and *Quart. Journ. Geol. Soc.* vol. xxxi. p. 152 (1875).

[9] J. G. Goodchild on the "Glacial Phenomena of the Eden Valley," *Quart. Journ. Geol. Soc.* vol. xxxi. p. 55.

[10] See H. Miller on Boulder Glaciation, *Proc. Roy. Phys. Soc. Edin.* vol. viii. p. 156.

[11] See J. Horne in *Trans. Geol. Soc. Edin.* vol. ii. Part iii. (1874).

[12] See the "Glacial Deposits of West Cumberland," by J. D. Kendall, *Trans. Cumb. Scient. Assoc.* Part vii.

[13] Sir A. Geikie in *Trans. Geol. Soc. Glasgow*, vol. i. 1863, and "The Great Ice Age," by Professor J. Geikie, third edition (1895).

[14] J. R. Kilroe on "Directions of Ice-flow in the North of Ireland," *Quart. Journ. Geol. Soc.* vol. xliv. p. 827.

[15] Notes on the Scenery and Geology of Ireland, *Proc. Liverp. Geol. Soc.* 1878-79.

[16] See papers by J. M. Mello in *Quart. Journ. Geol. Soc.* vol. xxxii. p. 240, and xxxiii. p. 589.

[17] "Bone Caves in North Wales," *Quart. Journ. Geol. Soc.* vol. xlii. p. 3, and xliv. p. 561.

[18] Sedgwick Prize Essay for 1876 (Cambridge), and *Mem. Geol. Survey*, the "Geology of Cambridge," p. 82. (1881).

[19] See especially W. A. E. Ussher on the "Post-Tertiary Geology of Cornwall," Dec. 2, vol. vi. p. 166 (1879), and A. R. Hunt, the "Raised Beach on the Thatcher Rock," *Trans. Dev. Assoc.* vol. xx. p. 225 (1888).

[20] F. W. Harmer, "The Influence of the Winds upon Climate during the Pleistocene Epoch," *Quart. Journ. Geol. Soc.* vol. lvii. p. 405 (1901).

[21] See *Quart. Journ. Geol. Soc.* vol. xl. p. 160, and the "Geology of East Lincolnshire," *Mem. Geol. Survey* (1887).

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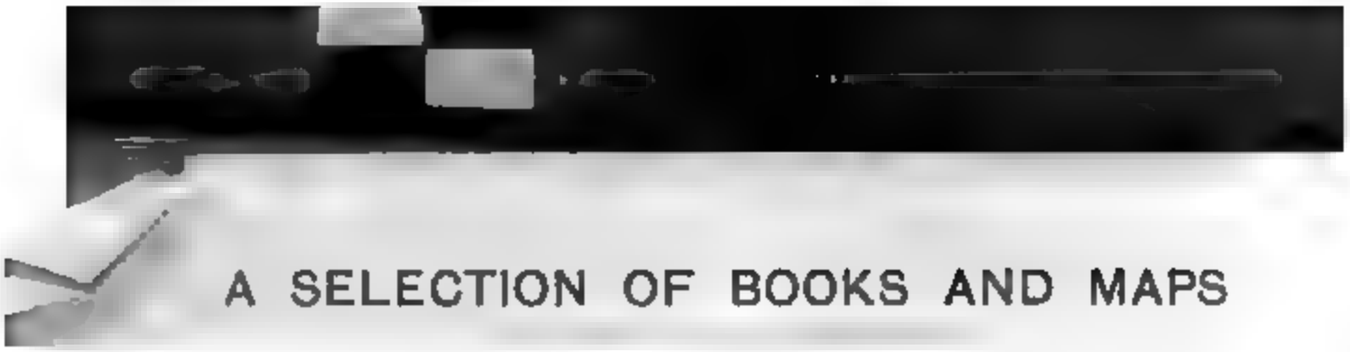

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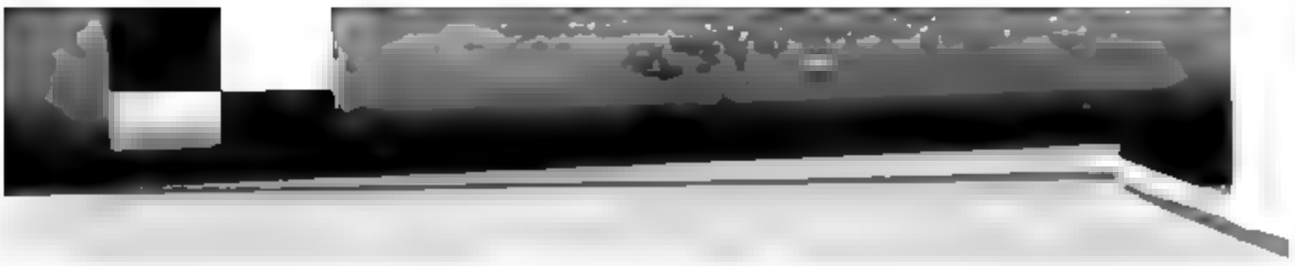

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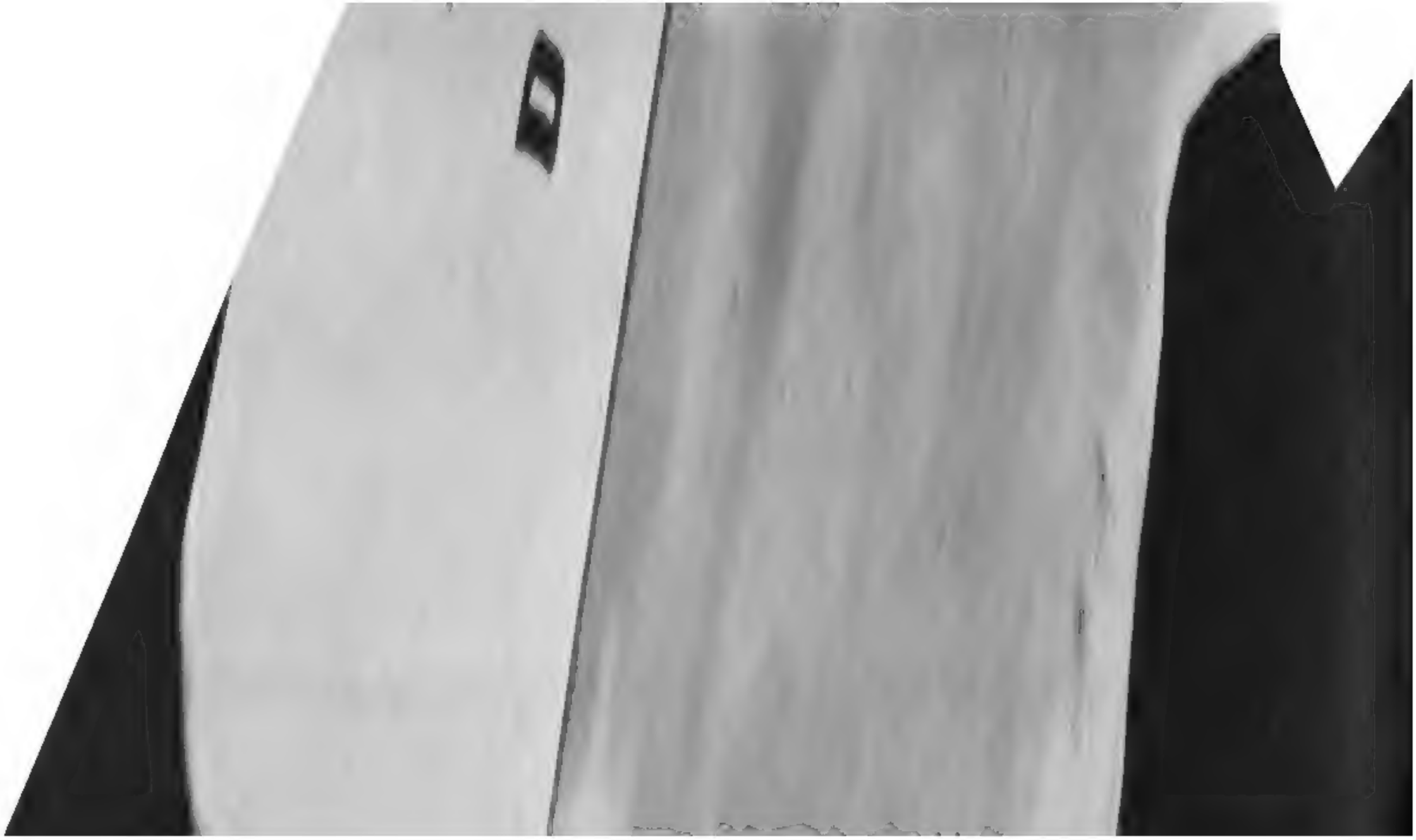
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